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AN INTEGRATED STUDY OF EARTH RESOURCES
IN THE STATE OF CALIFORNIA
USING REMOTE SENSING TECHNIQUES

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A report of work done by scientists of 4 campuses of the University of California (Davis, Berkeley, Santa Barbara and Riverside) under NASA Grant NGL 05-003-404

Semi-Annual Progress Report
31 December 1976
Space Sciences Laboratory
Series 18, Issue 5

UNIVERSITY OF CALIFORNIA, BERKELEY

AN INTEGRATED STUDY OF EARTH RESOURCES

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Principal Investigator:
Robert N. Colwell

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Chapter 1

Introduction

Robert N. Colwell

During the present reporting period we have continued to concentrate our University-wide remote sensing efforts on California's water resources. At NASA's request, however, the primary focus of our research has been changed from one of conducting remote sensing-related research to one of preparing "procedural manuals". The primary objective in preparing such manuals is to achieve technology acceptance. More specifically, the objective is to maximize the prospect that potential user agencies will adopt modern remote sensing techniques as an aid to the inventory and management of water resources, not only in California, but elsewhere as well.

Despite this change of focus, however, we have been able to progress toward the completion of those research aspects which will serve to establish the validity of the various step-by-step procedures which we are in the process of developing for inclusion in the manuals.

In keeping with the above, our present Progress Report consists of (1) a concise chapter-by-chapter account of research that our group has performed since 1 May 1976 and (2) based on this research, a first iteration of several Procedural Manuals, each of which deals with some specific way in which remote sensing can be used advantageously by the managers of water resources.

In conformity with our NASA-approved plan, these Procedural Manuals will soon be finalized, modifications being incorporated primarily as a result of user agency reaction. Furthermore the finalized versions will be prepared: (1) in both abridged and unabridged versions, the latter providing much more complete step-wise descriptions and documentation than the former and (2) in degrees of aggregation ranging from a single aspect per manual to all aspects. There will be for example, three separate Procedural Manuals relative to aspects of water-supply estimation by remote sensing -- those dealing, respectively, with snow areal extent, snow water content and evapotranspiration. These in turn will be compiled (with suitable integration to avoid repetition) into a single volume dealing with all aspects of the use of remote sensing in the estimation of water supply. Finally the integrated water supply volume will be further integrated with similar Procedural Manuals dealing with one aspect or another of remote sensing in relation to the estimation of water demand. Thus, the rather sizable overall document

will be for use of those concerned with all aspects of water resource management (both the supply and the demand aspects) while each of its various subdivisions, when made to stand alone, will better serve the needs of those concerned with only one limited aspect or another of this management problem.

As an additional aspect of our NASA-approved plan, (1) by 1 May 1977 we intend to bring to completion, or very nearly so, all of our remote sensing studies that pertain specifically to water resources, and (2) during the one-year period immediately thereafter, as we near the time of termination of the grant, we intend to concentrate on the preparation of Procedural Manuals that deal with remote sensing as an aid to the inventory and management of the entire "resource complex" of an area -- i.e. not just its water resources, but also its timber, forage, agricultural crops, soils, minerals, fish, wildlife, livestock, and recreational resources.

With respect to the preparation of these more comprehensive Procedural Manuals we recently have had discussions with various resource managers including (1) California's Regional Forester of the U.S. Forest Service; (2) the Supervisors of various U.S. National Forests in California; (3) their counterparts in California's State government; and (4) those concerned with resource management for representative county governments and private industrial groups. As a result of these discussions we have concluded that (1) in some instances it would be preferable from the intended user's standpoint for the Procedural Manual to deal with remote sensing as applied to only a single resource because the management objective, quite simply, is to obtain maximum production or benefit from that single resource, even at the expense of receiving reduced production or benefits from other resources that pervade the same area and (2) in other instances it would be preferable for the Procedural Manual to deal with remote sensing as applied to the inventory and management of multiple resources or, indeed, to the entire "resource complex". In instances of this second type the policy which the resource manager has been told to implement is one that recognizes the "trade-offs" that necessarily result when efforts are made to favor one resource over another. Hence, he has the non-trivial task of managing the entire property that has been entrusted to him in such a way as to provide an optimum "mix" of resource products. Reduced to its ridiculous extreme, this is the policy of attempting to provide what the first Chief of the U.S. Forest Service termed: "the greatest good for the greatest number". The concept would become considerably less ridiculous, however, if an integrated inventory were to be made with suitable rapidity and at suitably frequent intervals and providing suitably accurate information as to how much of each of the previously-mentioned components of the resource complex are present in each portion of the area that is to be managed. It, therefore, will

be our objective, as we produce this second type of remote sensing-oriented Procedural Manual, to present a step-wise procedure, complicated though it necessarily will be, for inventorying an area's entire resource complex. Consistent with NASA's wishes, that effort will be made (during the one-year period beginning on 1 May, 1977) primarily by three components of our multicampus integrated team: (1) the Geography Remote Sensing Unit on the Santa Barbara campus; (2) the Geosciences Remote Sensing Group on the Riverside campus, and (3) the Remote Sensing Research Program on the Berkeley campus. During that same period our Social Sciences Group also will be assisting in the preparation of the relevant manuals. By mutual agreement, the remote sensing team at Davis, under the leadership of Dr. Ralph Algazi, will not contribute to the preparation of Procedural Manuals during the one-year period that begins on 1 May, 1977. Instead his grant-funded efforts will be entirely in support of the ASVT that is jointly administered by NASA Goddard and the U.S. Army Corp of Engineers dealing with remote sensing as an aid to the estimation of water supply.

The proposed budget allocation for each of the above-named participating groups has been forwarded to our NASA monitors under separate cover.

A major part of the rationale for our having concentrated our remote sensing research on California's water resources for the past several years resides in the following facts:

(1) From the economic standpoint, water (rather than timber, minerals, forage, or recreation) is the most important resource obtainable from California's vast wildland areas, i.e. from the areas in which, because of difficulty of access on the ground, remote sensing is most needed.

(2) Since the supply of water that is present in California's wildland areas tends to fluctuate far more from season-to-season and year-to-year than does the supply of the other resources found there, the importance of remote sensing as an aid to the making of frequent and periodic inventories (i.e. to the "monitoring") of California's water resources becomes even greater.

(3) Virtually all of California's most important industry, agriculture, is very heavily dependent upon water. In fact, the water required to irrigate California's agricultural crops presently constitutes more than 80 percent of California's total water demand--the rest coming primarily from various industrial, commercial and domestic uses. Furthermore, just as the supply of this water can vary dramatically from season-to-season and year-to-year, so can the demand for it. Consequently, in view of the vastness of California's agricultural lands, and the frequency with which the water resource manager needs current, accurate information on the water demands that are being imposed by those lands,

remote sensing constitutes a means of great potential importance for the inventory and monitoring of water demand*

(4) Not only in California, but also in many other parts of the world, water is becoming an increasingly critical resource in relation to the economic well-being of mankind. It is probable that remote sensing techniques of the type which we have been developing for the inventory and monitoring of California's water resources could be applied, with only slight modification, to other parts of the world as well.

It is in light of the foregoing that the reader can better appreciate the potential significance of our efforts, as reflected in the present Progress Report, to develop Procedural Manuals relative to the use of remote sensing as an aid to the inventory and monitoring of water supply and water demand within the state of California.

*Documentation as to the great concern that currently exists relative to the adequacy of California's water resources, and therefore of the concern that exists relative to the adequacy of the information pertaining to the supply of and demand for those resources, is provided in the brief analysis which comprises Special Study No. 1 in Chapter 6 of the present Progress Report.

CHAPTER 2

WATER SUPPLY STUDIES BY THE DAVIS CAMPUS GROUP

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G. Ford
M. Suk

CHAPTER 2

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Semiannual Report, December 31, 1976
NASA Grant NGL-05-003-404

R. Algazi, Co-Investigator
Contributors: A Bhumiratana, J. Stewart, B. Romberger, G. Ford, M. Suk

I. Introduction and Overview

In the past three years, the research performed under this grant has focused on the application of remote sensing techniques to the study of water resources. Our group has studied some of the problems concerned with the supply of water in California. Hydrologic models have been implemented and analyzed, and studies have been conducted to determine by remote sensing some of the physical parameters which characterize the state of watersheds and the evolution of snowpacks. In addition to this systems engineering and modeling work, we have continued our technical work on digital image processing techniques for remote sensing applications.

In this report, we discuss the results of the research conducted during the past year, with an emphasis on the work performed since our May 1976 Annual Report. Significant results have been obtained in the following areas:

1. Implementation and sensitivity analysis of a watershed model and determination of hydrologic parameters amenable to remote sensing inputs.
2. Development of techniques for snowmelt runoff prediction based on digital processing of satellite images.
3. Basic studies of image processing techniques pertinent to remote sensing applications.

To facilitate the reading and understanding of this report, we have used appendices to explain the details of some of the image processing algorithms. This allows proper emphasis in the body of the report on the utility and significance of these procedures in achieving the grant objectives.

II. Implementation and Analysis of Hydrologic Models

During the past two years, we have conducted a study of hydrologic models which are intended to be used as operational tools to study the response of a watershed to various hydrologic, climatologic and meteorologic occurrences and to assess the effect of alternative land use patterns and hydraulic projects on this response. The hydrologic models of interest to us are basically of two types. The first type is intended to model the existing conditions on a watershed. Historical records of precipitation and runoff are typically used to calibrate these models. These models can be used by watershed managers to make timely and pertinent analyses regarding project operations decisions, such as the control of reservior releases. The second type of hydrologic model is intended to model anticipated or proposed changes in the characteristics of a watershed, such as residential or urban development and the construction of water retention or diversion structures. Our work to date has been concerned with a study of models of the first type, although some discussion of elements of models of the second type is given in section IV of this report.

We began our work on hydrologic models by reviewing the technical literature, and presented a discussion of our findings in the May 1975 Annual Report. Our subsequent work has been influenced by the work of

Ambaruch and Simmons [1] on the use of remote sensing in the Kentucky Watershed Model. Their work suggested that a quantitative assessment of the potential of remote sensing in watershed modeling be based on a study of the sensitivity of the output response of the model to variations in the input and internal model parameters.

We proceeded to conduct a sensitivity analysis of a streamflow model developed by Burnash, Ferral, and McGuire [2] for the River Forecast Center (RFC), operated jointly by the National Weather Service and the California Department of Water Resources. It was found that this analysis could not be carried out analytically, since some of the model parameters are determined by optimization procedures which are not amenable to analytical study. Due to this problem, the sensitivity analysis was performed by computer simulation. The RFC model, made available to us by Burnash and Ferral, was implemented on two computers on the Davis campus in March 1975.

The RFC model consists of a main program known as the soil moisture model, and a major subroutine known as the snow submodel which generates equivalent precipitation from snowmelt for use in the soil moisture model. The soil moisture model has been implemented at Davis, and simulation results have been generated for the Middle Fork of the Feather River, using historic data on precipitation and runoff from 1962 to 1969.

To support our ultimate objective of determining the utility of the use of remote sensing data as an input for this model, we pursued the following specific objectives:

1. Analysis of the model: To acquire, by simulation and analytic study, some insight into the behavior of the hydrologic model.
2. Sensitivity study: To study the effect of variations in the

dynamic inputs and internal parameters of the model on the predicted runoff. Emphasis is placed on those parameters which can possibly be acquired by remote sensing.

3. Simulation: To use parameters and inputs acquired by remote sensing in the model and to determine the effect of these parameters on the predicted runoff.

Parts 1 and 2 above have been completed for the soil moisture model, and a comprehensive discussion of the results was presented in the May 1976 Annual Report. In the sensitivity analysis, the effect on monthly volume runoff of variations in the parameters representing precipitation (rainfall and snowmelt), evapotranspiration, lower zone and upper zone tension water capacity, the percent imperviousness of the watershed, and the percent of the watershed in riparian vegetation, streams and lakes was studied. The most sensitive and critical parameters were found to be precipitation during the entire year, and evapotranspiration, principally for the spring regime of the model. From this result, we can conclude that precipitation and evapotranspiration are the most important parameters to acquire by remote sensing techniques. Since snowmelt is a component of precipitation, the determination of snowmelt by remote sensing is also an important task.

Model simulations incorporating information acquired by remote sensing are currently in progress. A cooperative study of the effect of acquisition of evapotranspiration by remote sensing will be made by our group and the Titus group of the Remote Sensing Research Project (RSRP) in Berkeley. The Titus group has developed a technique for the estimation of evapotranspiration from remotely sensed data. They will apply this technique to the Middle Fork of the Feather River for the Spring season of 1975. Our

group will use their estimated evapotranspiration parameters as an input to the RFC model to simulate the Spring 1975 conditions. Problems with this approach have recently been encountered, and must be resolved during the coming year. In order to perform the desired simulations, it is necessary to acquire daily volume runoff data for the Middle Fork at Merrimac and daily precipitation data for five stations within the watershed. The runoff data and raw precipitation data are available from the California Department of Water Resources. However, in order to run the simulation, the raw precipitation data must be preprocessed using the snow submodel. R. L. Ferral of the River Forecast Center has indicated that the work entailed in this preprocessing is substantial, and that his organization does not plan to do this work in the immediate future. In addition, he stated that the snow submodel program has not been adequately documented, so that it would not be possible for our group to do the precipitation preprocessing. A meeting with personnel from the River Forecast Center is planned for early 1977 to attempt to resolve these problems.

We are presently developing a model for the prediction of snowmelt runoff prediction which has a strong reliance on data acquired by remote sensing. At the present time, we do not anticipate incorporating our snow model with the RFC model. Rather, we intend to develop an independent snowmelt model which will demonstrate the feasibility of the use of remote sensing in the prediction of snowmelt runoff. Our work in this area is discussed in greater detail in the following section.

III. Snowmelt Runoff Prediction

Our work with hydrologic models primarily concerns the development of dynamic models for the prediction of runoff due to snowmelt, in which satellite data is the principal dynamic input. On the basis of previous research in this area, the following physical quantities are of primary interest in the modeling of basinwide snowmelt: the temperature, albedo, water content, and the elevation, slope, aspect and areal extent of the snow; the spatial distribution of precipitation; and the properties of the vegetal canopy. It is well known that these parameters vary substantially across the snow covered area within a major watershed and that they can change rapidly with time. For these reasons, we have undertaken a study to incorporate satellite data into a physically based, spatially distributed model of snowmelt for basinwide runoff prediction.

Since the snowpack evolves rapidly, and we wish to develop a dynamic model of snowmelt runoff, we have chosen to use the daily coverage provided by the NOAA satellites as our principal remote sensing data source. In addition to the daily coverage, the NOAA satellites provide data in a thermal infrared band (10.5 to 12.5μm) as well as in a visible band (0.5 to 0.7 μm). However, we will not restrict the input data solely to remote sensing sources. Other easily obtained data will be incorporated, including: LANDSAT images, digitized elevation data, temperature and precipitation records from ground stations within the watershed, snow survey data and daily volume runoff data.

Our approach to modeling the snowmelt is to first apply pattern recognition clustering analysis to the spatially distributed data to partition the watershed into regions which are homogeneous in terms of the available

remotely sensed parameters. Submodels will then be developed to predict the localized snowmelt runoff on each of these regions. Standard hydrologic techniques of streamflow routing and combining will be applied to the localized runoff in order to predict the basinwide snowmelt runoff.

The model will be developed and tested on the Kings River basin of the southern Sierra Nevada range. This basin was selected because it is typical of the Sierra Nevada watersheds. It is a diverse watershed, ranging in elevation from about 500 feet at the outlet below Pine Flat Lake on the west to over 14,000 feet along the crest of the Sierras on the eastern edge of the watershed. The Kings River has three forks, the North, Middle, and South, and flow has been impaired only on the North Fork at Courtright and Wishon Reservoirs and on the main channel at Pine Flat Lake which is below the confluence of the three forks. A map of the watershed is shown in figure 1.

We chose to study the spring 1975 snowmelt season because of the availability of NOAA satellite data for this period. Coincidentally, the precipitation for winter 1974-1975 for the Kings River region was very close to the historical average values, so our study is for a near normal water year. We acquired all usable data collected by the NOAA-3 and NOAA-4 satellites over California, both in the visible band and in the thermal infrared band, from April 1, 1975 to July 7, 1975. We have data for 24 dates, but the data for the 9 dates in April are missing every third line of the image data because some of the user agencies were unable to handle the full data rates prior to early May 1975, and every third line was deleted in order to reduce the data load.

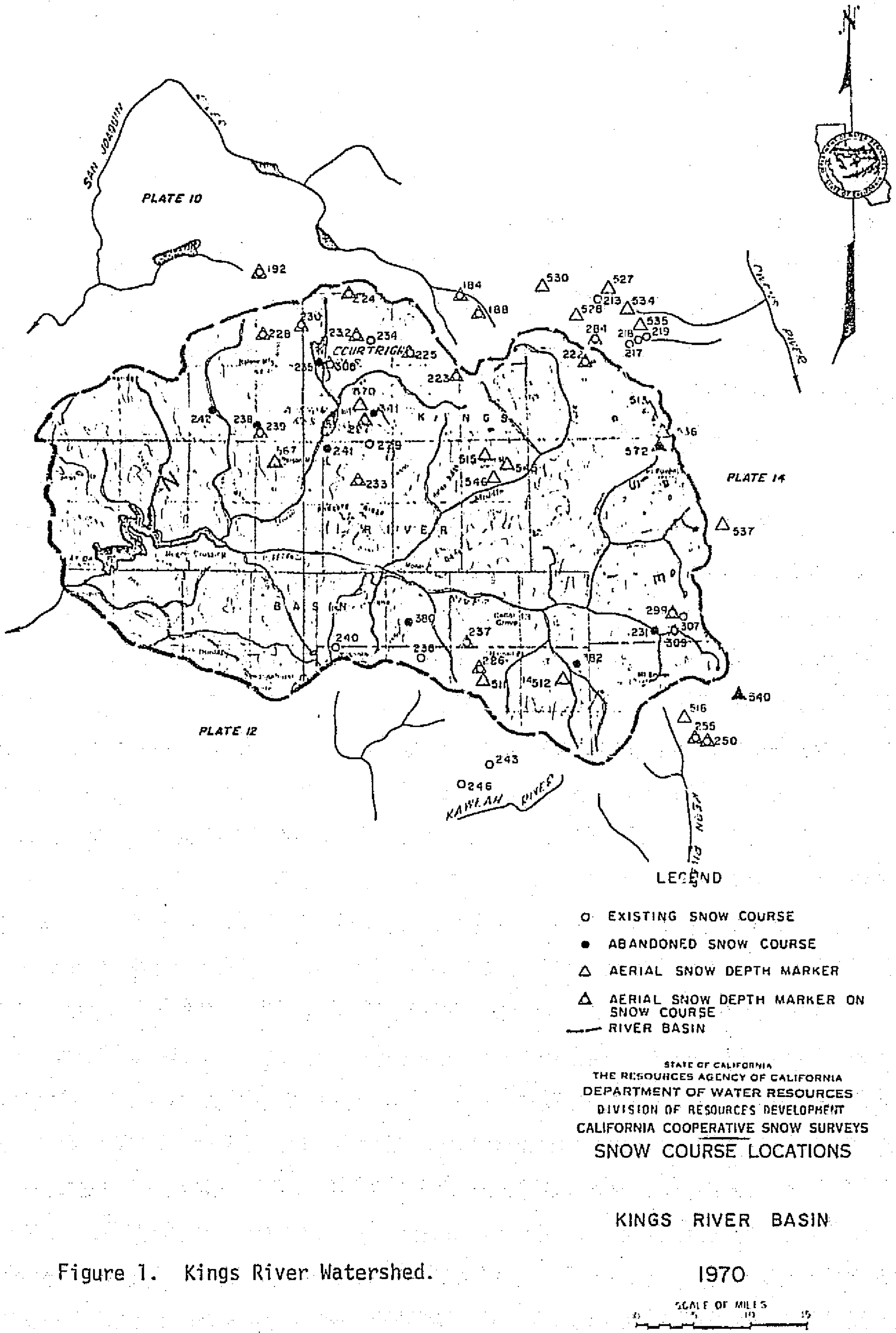


Figure 1. Kings River Watershed.

We have attempted to obtain all of the ground truth data which is available for the Kings River basin for the first half of 1975. Charles H. Howard, an Associate Water Resources Engineer with California DWR has provided us with a wealth of hydrologic data, including: daily temperatures for Grant Grove and Balch Power House; daily water equivalent of the snow pack as measured by snow sensors at State Lakes, Mitchell Meadow and West Woodchuck Meadow; monthly snow survey data for 22 snow courses; and daily unimpaired flow by Pre-Project Piedra, below Pine Flat Lake. A plot of the daily water equivalent of the snow pack is shown in figure 2, and a plot of the unimpaired flow is shown in figure 3.

Digital terrain tapes prepared by the Department of Defense, Defense Mapping Agency, from the USGS 1:250,000-scale topographic quadrangle map series were obtained from the National Cartographic Information Center for the Mariposa, California, and Fresno, California quadrangles. The data on these tapes has been converted into digital image format, and has been placed in registration with the NOAA satellite images, as will be discussed later in this report.

We have also obtained a computer-compatible tape (CCT) of the LANDSAT 2 image for September 1, 1975. Both the cloud cover and the snow cover are negligible on this date, and the imagery covers the entire extent of the Kings River basin. This imagery will be analyzed to determine the vegetative cover within the watershed.

NOAA Satellite Image Geometric Correction

In order to analyze the available data, and to convert it into a format which is suitable for input to a snowmelt model, we have been working to establish a file of spatial and temporal data consisting of albedo,

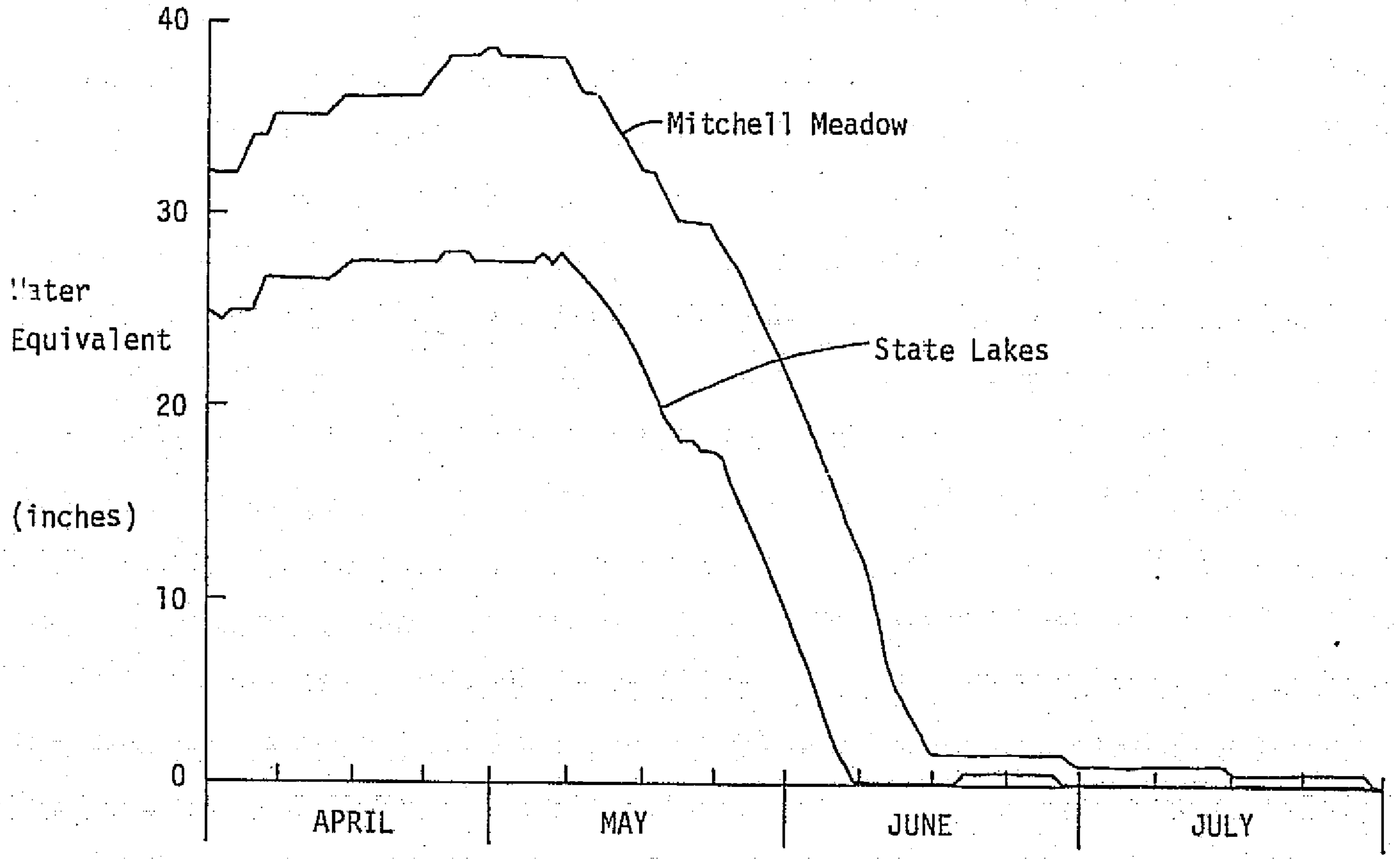


Figure 2. Daily Water Equivalent of Snow Pack

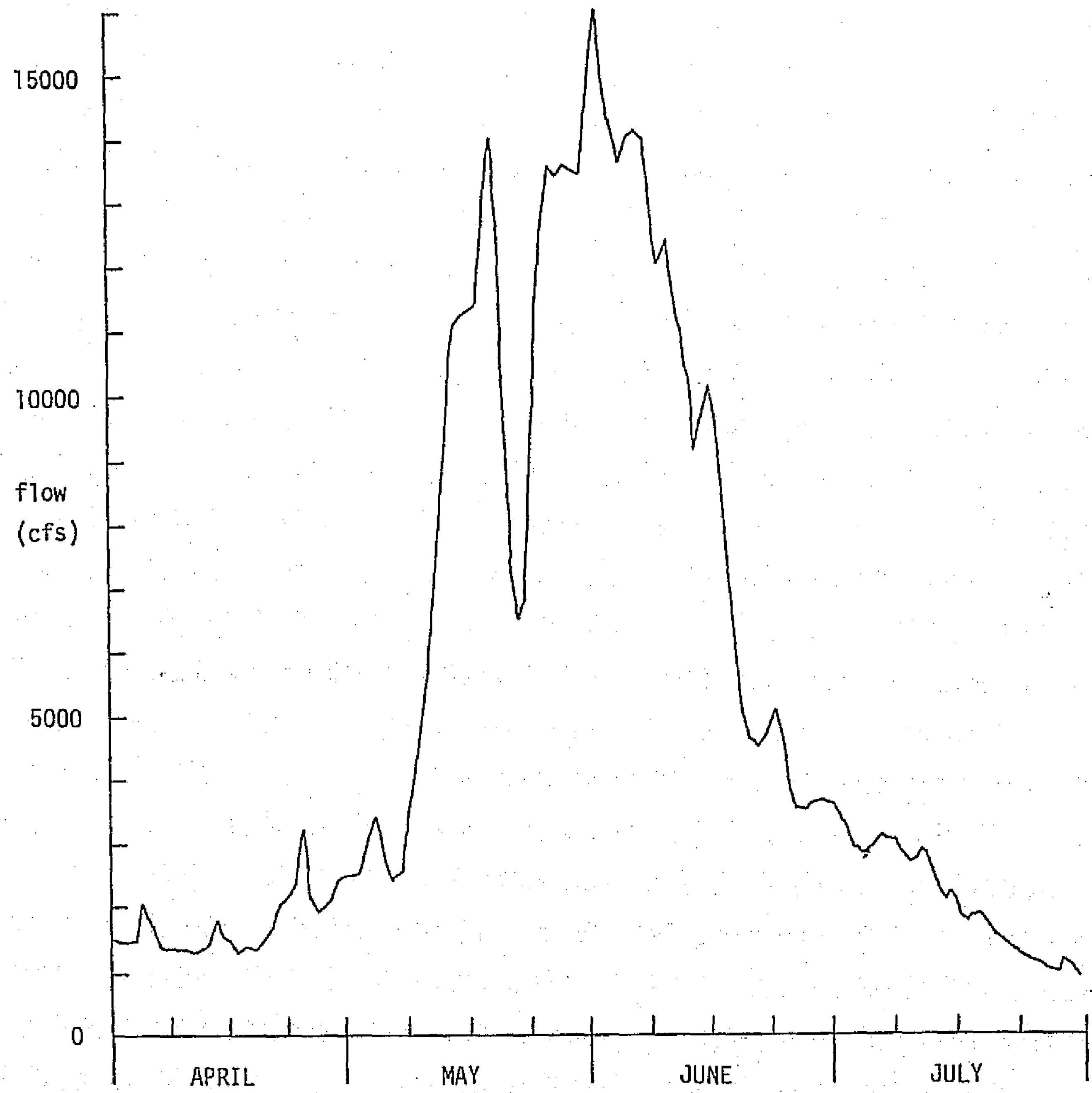


Figure 3. Unimpaired Daily Average Flow at Pre-Project Piedra

temperature, and elevation. For each date for which we have NOAA data, we want to be able to determine the albedo, temperature and elevation of any point within the watershed. With this capability, we can study the dynamic behavior of the snowpack. To establish this file, we must be able to achieve multitemporal registration of the NOAA images.

In order to obtain multitemporal registration, the geometric distortion present in the images must be removed. This distortion is due to a number of sources, including the scanning motion and orbital characteristics of the satellite, and the curvature and motion of the earth. This distortion varies from day to day due to the variation in location of the satellite with respect to a given point on the ground at the time the image is acquired. Thus, geometric correction is a crucial issue in our attempts to employ this form of remote sensing data.

A general discussion of techniques for geometric correction of satellite images is given in section IV of this report; however, a summary of the techniques applied to the NOAA images will be given here, and the details of these techniques are given in the appendices.

A two step geometric correction procedure is applied to the NOAA images. An example of a raw data image of south-central California on May 16, 1975 is shown in figure 4. A comparison of this image with a map of the region clearly demonstrates the distortions in this image, due primarily to the panoramic distortion caused by the earth's curvature and the skew distortion caused by the earth's rotation. This primary distortion is removed by a nonlinear resampling algorithm which is based on a model describing the distortion which was developed by Legeckis and Pritchard [3]. In this algorithm, which is discussed in detail in Appendix A, two-point interpolation resampling is applied along each image scan line

Figure 4. Uncorrected NOAA-4 Visible Image for May 16, 1975

independently. The resulting images still possess a variable degree of rotation, which is a function of the satellite position at the time of image acquisition, and other residual distortions, which were not accounted for in the correction algorithm. In the second step of the geometric correction procedure, the residual distortion is corrected by transforming the image using a biquadratic mapping function. Ground control points (GCPs) are used as external reference information to determine the proper mapping function. A GCP is a physical feature which is easily detectable in the image and easily located on a map. In this work, the GCPs used are water-land interfaces, such as the shorelines of lakes, the coastline near Monterey Bay, and features of major rivers. The locations of as many as 125 GCPs are determined from the partially corrected image and from USGS 1:250,000 scale topographic maps. The coefficients of the mapping function are then selected to minimize the squared distance between the GCPs in the image and the transformed GCPs from the maps. The image is then transformed, and examples of the results for the images of May 16 and May 24, 1975 are shown in figures 5 and 6. Details of this procedure are given in Appendix B.

An analysis of the remaining mean-squared errors of the GCPs indicates that the geometric correction procedure is correct to within one pixel in the output image. A summary of the results obtained for the four separate dates which we have worked with is shown in the table below:

Date	GCPs	MSE
May 16	124	0.740
May 24	111	0.798
May 28	120	0.823
May 29	103	0.508

While the results above show that the geometric correction procedure is effective, we have found that it is not entirely adequate due to the fact that it is very time-consuming. Determining the locations of over 100 GCPs in a 512x512 image is a very tedious task, even though we are able to do this by moving a cursor across a video display of the image. Our analysis of the procedure indicates that by eliminating some of the unreliable GCPs, we should be able to correct the image to nearly one pixel by using only 30 GCP's. However, this would still be a tedious procedure to apply to over 20 images, so we are currently developing an alternative approach to the geometric problem.

Development of a New Geometric Correction Algorithm

In our new approach, we still apply the algorithm to correct for panoramic and skew distortion. We then will calculate the amount of rotation in the image from a knowledge of the satellite orbital parameters. A simple bilinear transformation can then be applied to remove this rotation. The resulting image will only possess minor residual distortions. At this point one of the images which has been corrected using the previously described procedure will be selected as a reference image in determining the transformation to be applied to remove the residual errors. We will compute cross-correlation matrices between the reference image and the partially corrected image on several small, selected regions which have high contrast features. The locations of the maximum value of each of these cross-correlation matrices will be used as a virtual control point in the determination of the coefficients of a biquadratic transformation.

Figure 5. Geometrically Corrected NOAA-4 Image for May 16, 1975

Figure 6. Geometrically Corrected NOAA-4 Image for May 24, 1975

Correction of Radiometric Errors in NOAA Thermal Images

In addition to geometric correction, it is necessary to correct the errors in the thermal infrared image which are due to a drift in the sensitivity of the sensors. These random errors appear as horizontal banding or striping in the image. We have developed a digital filtering algorithm to remove these errors. A NOAA calibration algorithm is then applied to convert the numerical thermal image values into temperature. Details of our work to correct the early NOAA procedure have been discussed in earlier reports.

The final error which must be corrected is a random mis-registration of the thermal and visible images which is due to causes unknown to us. To correct this error, we first align the images as close as possible by eye, then we select regions of the image which contain high contrast features and compute the cross-correlation between the two images over these regions. The maximum cross-correlation determines the amount of horizontal and vertical translation required. We are able to register the two images to within one pixel with this procedure.

Elevation Data Correction

The elevation data on the digital terrain tapes which were mentioned provіously also had to be corrected in order to put them in registration with the NOAA images. The terrain data is taken from a universal transverse mercator (UTM) grid, in which degrees longitude and latitude are given uniform spacing. However, the satellite data was corrected to have uniform distance spacing, so it was necessary to apply a map-to-map transformation to the elevation image. The resulting image is shown in figure 7,

with a corrected NOAA visible image for May 24, 1975 covering the same area shown in figure 8 for comparison.

Future Work on Kings River Modeling

We plan to continue our work to simplify the procedure for geometric correction. When this is complete, we will apply the correction procedure to as many of our available NOAA images as is practical.

We will continue our work on the development of a snowmelt runoff model for the Kings River basin. Trial runs of this model are planned for late spring or summer 1977.

IV. DIGITAL IMAGE PROCESSING TECHNIQUES DEVELOPMENT

Our efforts in the specific technical field of digital processing have followed two parallel goals: to pursue vigorously the specific areas of work in which we feel we can make a valuable contribution and to incorporate into our facility the algorithms and techniques developed by others which seem to have the most merit in applications.

A. Geometric Correction of Satellite Images

As discussed in section III, remote sensing data acquired by satellite sensors are affected by geometric distortions that, if uncorrected, diminish the accuracy of the information extracted and thereby reduce the utility of the data. The raw data image is an array of digital data which represents a geometrically distorted, two-dimensional perspective projection of some portion of the Earth's surface. The desired image is a geometrically corrected map projection of the same ground area.

The principal geometric errors associated with the data received from a satellite are the following:

Figure 7. Digital Elevation Image

Figure 8. Portion of Geometrically Corrected NOAA-4 Image for May 24, 1975

(1) Panoramic distortion - Data samples are taken at equi-angular intervals of the scanning mirror motion, which means that the data does not come from regular intervals along the ground. This produces a nonlinear stretching of the image along scan lines.

(2) Earth rotation - During the image acquisition, the earth rotates beneath the sensor. This causes both along-scan and cross-scan distortion.

(3) Scan skew - During a line scan, the satellite moves along a ground track. Thus the ground swath swept out by the sensor is not normal to the ground track but is slightly skewed, which produces cross-scan distortion

(4) Velocity - If the satellite velocity varies, the spacing of image samples on the ground will vary, causing a cross-scan scale variation.

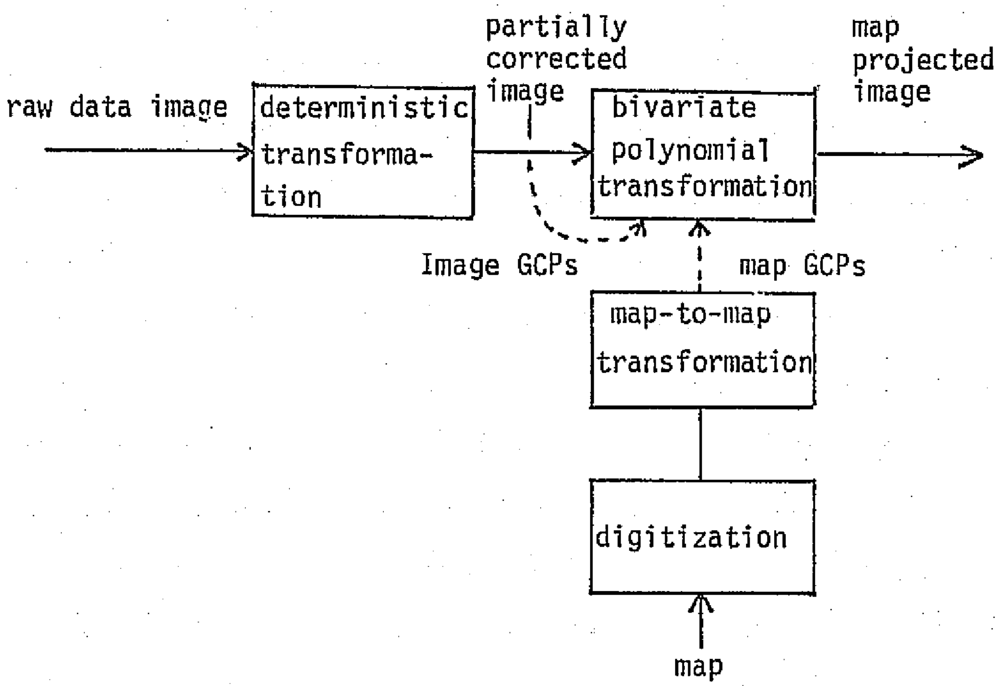
(5) Altitude - Due to the non-circular nature of the satellite orbit, and the non-spherical nature of the Earth's surface, the space-craft altitude of the satellite varies, causing scale changes in the image data.

(6) Attitude - If the attitude of the satellite varies from the nominal values, geometric distortions will result.

(7) Mirror velocity - If the scanning mirror rotates at other than the nominal constant angular rate, along-scan geometric distortion will occur.

Geometric correction procedures are applied to the distorted received images to transform them to a desired map projection. Most of these procedures are composed of two major steps, and require the use of external

reference information obtained from maps. An overview of the procedure is shown in block diagram form below:



In the first step, a model is developed to describe the known image distortion as accurately as is possible. A deterministic correction transformation is then synthesized from the model, utilizing the satellite orbital parameters to adjust the transformation. An example of a deterministic correction procedure developed for NOAA satellite data is given in Appendix A. The deterministic correction produces a partially corrected image which contains residual distortions due to random errors or to deterministic errors which were not accounted for in the deterministic transformation.

In the second step of the generalized geometric correction procedure, external reference information is used to characterize a bivariate polynomial image transformation which is used to transform the partially corrected image to the desired map projection. Ground control points (GCPs) are used to

obtain the external information. A GCP is a physical feature which is easily detected in the image and easily located on a map. The most reliable GCPs are land-water interfaces, but airports, highway intersections, geological features, or agricultural field boundaries can also be used. The locations of these GCPs must be determined in the partially corrected image (dotted line labeled image GCPs in the figure above). The actual locations of the GCPs must be determined from a map (or several maps). This is typically accomplished by first digitizing the GCP locations on the map using a digitizing table or a graphics tablet. This establishes the GCP locations in the coordinate system of the digitizing instrument. It is then necessary to perform a map-to-map transformation on this data to transform it to the desired coordinate system of the map projected image. This transformation generally consists of scaling and translation, but can also entail a transformation from one mapping system to another. The outputs of the map-to-map transformation are the map GCP's. The coefficients of the bivariate polynomial transformation are then selected so as to minimize the sum of the squared errors between the image GCPs and the transformed map GCPs. A network of grid points in the map projection coordinate system is mapped into the coordinate system of the partially corrected image. After determining the location of the output pixels in the input image, the image is resampled using a bilinear interpolation method which uses four neighboring input values to compute the output intensity by two-dimensional interpolation.

We are actively trying to refine and improve on this procedure. Our first step is the development of interactive software for use with a graphics tablet and a minicomputer which will allow us to digitize GCPs from maps, and then to analyze the effect each GCP has on the resulting

transformation. With this software, we will easily be able to eliminate those GCPs which appear to have been unreliably located in either the image or the map. Secondly, we are developing procedures which will eliminate the need for the tedious acquisition of GCPs. Using a reference image which has been geometrically corrected, we will select small, high contrast regions in the image and compute a cross-correlation matrix between the reference image and a partially corrected image. The location of the maximum of the cross-correlation matrix will be used as a virtual GCP. The virtual GCP should be more accurate than the previously obtained GCPs, and will lead to a better correction transformation.

B. Acquisition of Ground Truth Information

In support of our work involving the use of remote sensing data in hydrologic modeling, we frequently need to acquire information from maps. Examples of the data required are: locations of ground control points, watershed boundaries, and boundaries of contiguous land use regions.

In order to meet this requirement we are developing software to allow interactive digitization of map information, using a graphics tablet and terminal interfaced to a minicomputer. The interactive capability will allow us to detect and correct errors during the process of digitization, which will provide improved accuracy.

C. Land-Use Classification

For the development of hydrologic models which are intended for use in analyzing proposed or anticipated changes in watershed characteristic, important information which can be acquired by remote sensing is the classification of existing land use.

We are presently exploring procedures for determining land use which are based on the efficient use of satellite image data and ground truth

information. Using LANDSAT data, we have applied algorithms for maximum likelihood classification to the Trail Creek watershed near Athens Georgia. We found that this approach was not adequate, due to the difficulty in the selection of training fields which were representative of the land uses within a small watershed. We are presently exploring the application of clustering algorithms to land use classification to determine the natural groupings or classes within the image data. This approach has been applied to two watersheds: Trail Creek, and Castro Valley, California. The results have been very promising and an example is shown in figure 9. We are also investigating the use of texture information in the clustering algorithms.

Another area of current research is an investigation of the relationship between land cover, which can be remotely sensed by a satellite, and land use, which is the desired information. The goal of this study is to determine which land uses can be reliably estimated from land cover information. This will lead to a list of land uses which can be determined by remote sensing.

D. Improvement of Processing Capability

In the past six months a digital image processing facility has been acquired by the Department of Electrical Engineering at UC Davis. The facility is currently operational, and work is under way to implement a software picture processing system and to transfer software from the Picture Processing Facility at UC Berkeley. Beginning in March 1977, the transition will be completed and all of our image processing work will be conducted at the Davis facility.

A block diagram of the new facility is shown in figure 10. The major hardware elements are as follows:

Figure 9. Land Use Classification by Clustering for the Trail Creek Watershed Near Athens, Georgia

1. The digital processor is a DEC, PDP 11T55 Fast Fortran Laboratory System. This extremely fast minicomputer includes 32,768 words (16 bit) of memory, a fast asynchronous Floating Point Processor, a DECwriter, and 2 RK 05 disks with a total storage of 4.8 million 8-bit bytes.

2. A 285 card per minute card reader.

3. One Kennedy Model 9300, 9 track 125 IPS, Dual Density 800/1600 BPI tape drive. The 1600 BPI density is unique on campus for this very fast digital tape drive.

4. A Tektronix 9054 X-Y digitizing tablet. The size is 30" x 40" and the resolution is .01".

5. A large disk (not acquired yet because of lack of funds).

6. Printer-Plotter. Versatec 1200A, 11" wide and 200 dots/inch. Versaplot 1 software package.

7. Image display system. Model 70 manufactured by International Imaging System (I^2S). This display system includes powerful video rate processing capability. A 256 x 256 full color image is refreshed digitally. Three overlays are available.

8. Color television monitor. A high quality 19" Conrac color monitor.

9. High resolution CRT. A black-and-white precision recording cathode ray tube with a 70 mm camera. This unit will be modified to allow the photography of 1024 x 1024 full color images by the use of sequential filters.

10. Image scanner. Not available. A 512 x 512 unit will be built at the earliest possible time.

A Tektronix 4014 graphics terminal with supporting software will also be connected to the PDP 11/55.

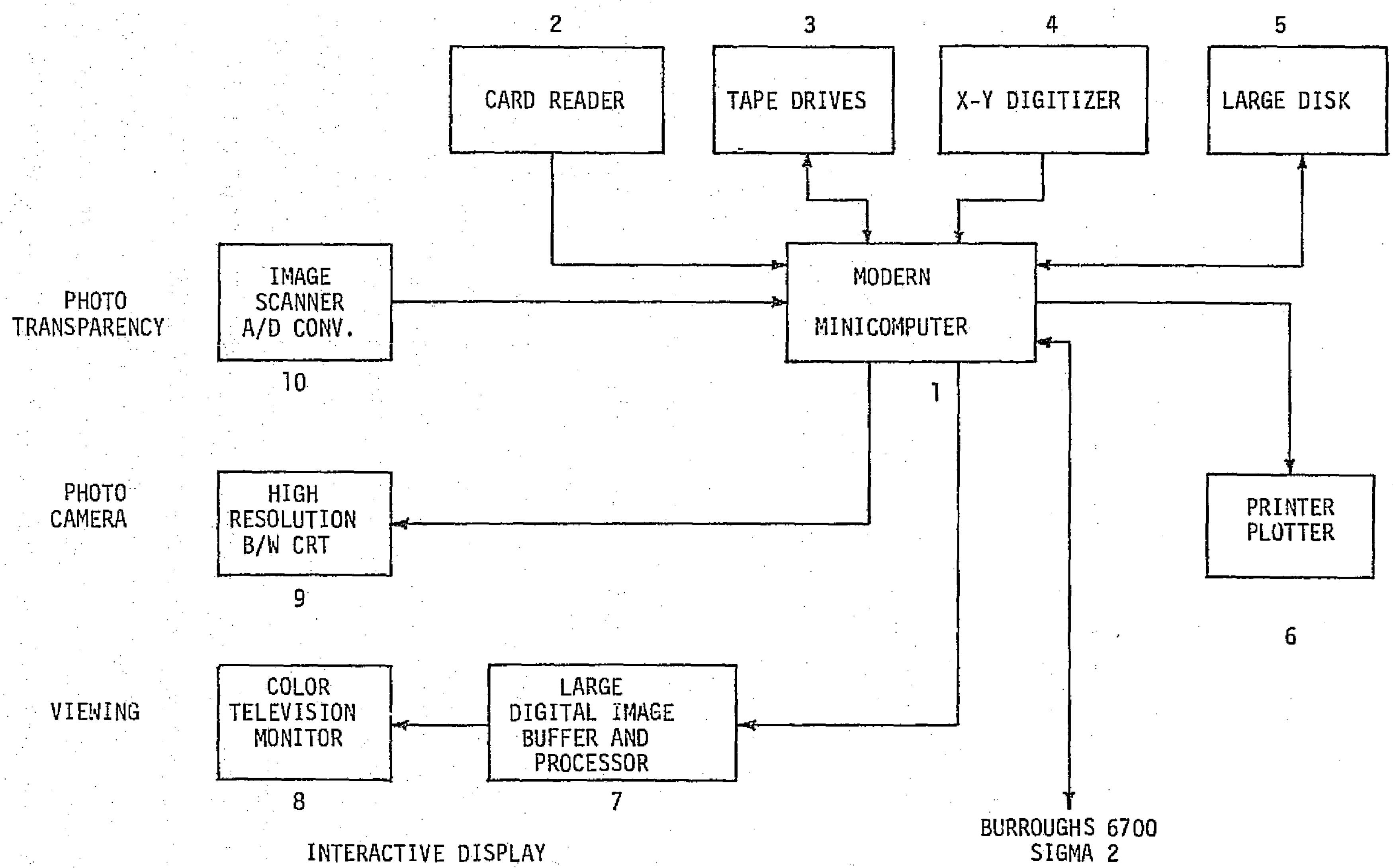


Figure 10. DIGITAL IMAGE PROCESSING FACILITY

V. PUBLICATIONS AND TECHNICAL PRESENTATIONS

1. B. J. Fino and V. R. Algazi. "Unified Matrix Treatment of the Fast Walsh-Hadamard Transform" IEEE Trans. on Comp., vol. C-25, no. 11, pp. 1142-1146, Nov. 1976.
2. V. R. Algazi, "Remote Sensing", A technical presentation at the 3rd Infocorp Assoc. Meeting (USACE Automatic Data Processing Conference), Davis, Calif., Aug. 17019, 1976.
3. V. R. Algazi, "Image Processing in the Application of Remote Sensing to Hydrology". Invited presentation at the US-Japan Seminar on Image Processing in Remote Sensing, College Park, Md., Nov. 1-5, 1975.

VI. PROPOSED AND CONTINUING WORK FOR 1977

The work under this multicampus University of California grant is being phased out over the coming year. By agreement with Dr. R. N. Colwell and the NASA monitor the work on our portion of the grant will be principally concentrated on support work in digital image processing for the ASVT program co-sponsored by NASA and the Corps of Engineers. Hence 1 and 2 below represent the phase out work on the "Integrated Study" grant. Item 3 is being continued until May 1978.

1. Simulation work on RFC hydrologic model using evapotranspiration parameters acquired by remote sensing, in cooperation with RSRP, Berkeley.
2. Basic work on the use of NOAA data as an input to a snowmelt runoff model:
   - data correction
   - geometric correction
   - development of distributed snowmelt model
   - statistic prediction of runoff
   - trial simulations of model

3. Digital image processing work in support of our work on hydrologic modeling:

- . geometric correction
- . digitization of map information
- . land use classification

Part of the budget requested in the period May 1, 1977 to May 1, 1978 will be used in the acquisition of computer peripherals for our work in the operational application of remote sensing in hydrology.

VII. REFERENCES

1. R. Ambaruch and J. W. Simmons, "Developments in Applications of Remote Sensing to Hydrology Through Continuous Simulation", Remote Sensing of Earth Resources, vol. II, Proc. of the 2nd Annual Remote Sensing Conference, Tullahoma, Tennesses, March 1973, pp. 1287-1306.
2. R. J. C. Burnash, R. L. Ferral, and R. A. McGuire, "A Generalized Streamflow Simulation System", River Forecast Center, Sacramento, California, March 1973.
3. R. Legeckis and J. Pritchard, "Algorithm for Correcting the VHRR Imagery For Geometric Distortions Due to the Earth's Curvature and Rotation", NOAA Technical Memorandum, Washington D.C., January 1976.

APPENDIX A

Deterministic Geometric Correction Algorithm for NOAA Satellite Data

The principal geometric distortions in the NOAA Very High Resolution Radiometer (VHRR) images are due to the fact that the line scans are made along the curved and rotating Earth's surface. As a result, the distance between samples as well as the area of the scene in the VHRR field of view varies as the distance from the nadir increases. Although other variables contribute to the geometric distortion of the images, the principal distortions can be eliminated by correcting the errors due to the curvature and rotation of the Earth.

Radiometer Characteristics

The radiometer, as described by Schwalb [A1], is a two-channel scanning instrument sensitive to energy in the visible spectrum (0.5 to 0.7μm) and the thermal infrared spectrum (10.5 to 12.5μm). The scanning instrument is designed to operate on a spacecraft with a sun-synchronous orbit having a nominal altitude of 1501 km. Energy is gathered by an elliptical scan mirror which is set at an angle of 45° to the scan axis and rotates at 400 revolutions per minute. The reflected energy is focused by a Cassegrainian-type optical system and is detected by a silicon photo-voltaic detector in the visible range and a thermistor bolometer in the infrared range.

The NOAA-3 and NOAA-4 satellites are operated in polar orbits. Over the western portion of the U.S., the satellite moves toward the southwest, in an orbit having an inclination angle (Q) of 78° at the equator, as shown in figure A-1.

The scan mirror of the radiometer rotates at a constant angular velocity and the visible and infrared detectors are sampled at a uniform rate(s) of 106,666 samples per second, so the acquired data is the same as would be

obtained from a device having uniform angular sampling as shown in figure A-2.

Assumptions

In order to simplify the geometric correction procedure, the following assumptions are made:

1. The Earth is a sphere with radius (R) of 6371 km which rotates on its north-south axis with a constant period (T) of 24 hours.
2. The following satellite parameters are assumed constant:

   orbital angle of inclination of the equator, Q = 78°

   orbital period, $P = \begin{cases} 116.1 \text{ min for NOAA-3} \\ 115.0 \text{ min for NOAA-4} \end{cases}$

   data sampling rate, S = 106,666 samples per second

   angular scan rate, W = 400 revolutions per minute

Correction for Panoramic Distortion

Panoramic distortion appears in the VHRR images as a contraction of the Earth's features at increasing distance from the nadir. To remove this distortion, an algorithm must be applied to resample the original data so that the new sample points correspond to equi-distant spacing on the ground. The panoramic correction procedure discussed here is based on an algorithm developed by Legeckis and Pritchard [A2].

First refer to figure A-3 to determine the relationship between the radiometer scan angle (α) and the geocentric viewing angle (ϕ). It can be shown that

$$\tan(\alpha) = \frac{x}{h_o + \Delta h} = \frac{R \sin(\phi)}{h_o + R - R\cos(\phi)} = \frac{\sin(\phi)}{\frac{h_o + R}{R} - \cos(\phi)}$$

or

$$\alpha = \tan^{-1}\left[\frac{\sin(\phi)}{\frac{h_o + R}{R} - \cos(\phi)}\right], \qquad \text{(A-1)}$$

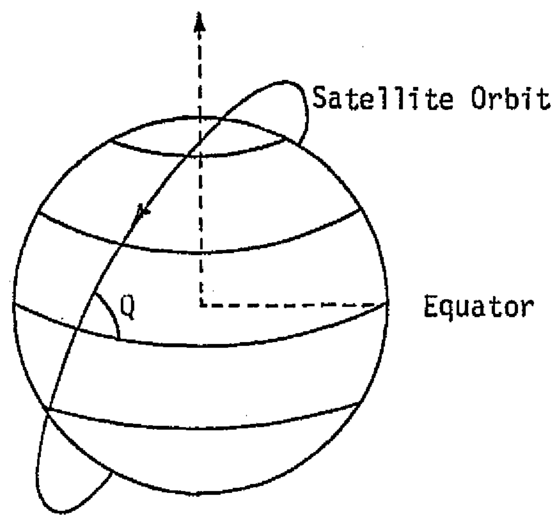


Figure A-1

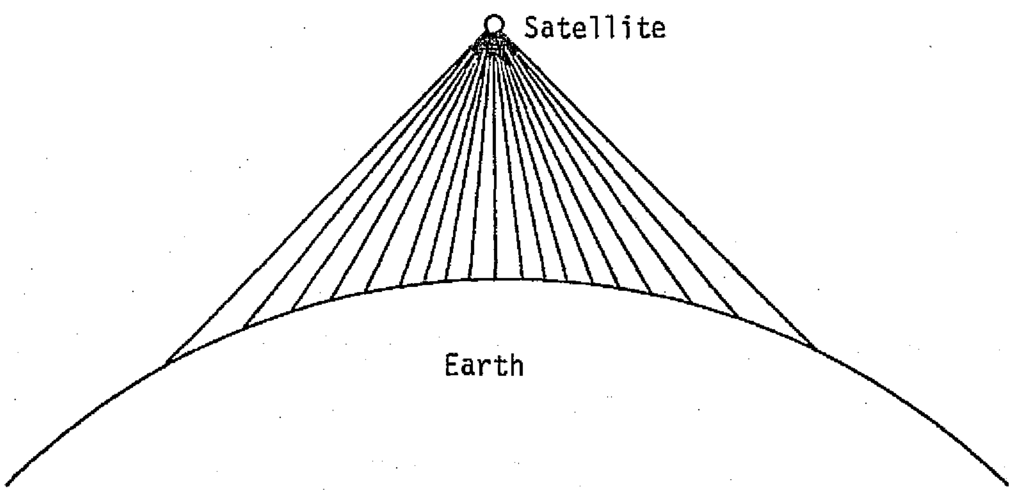


Figure A-2

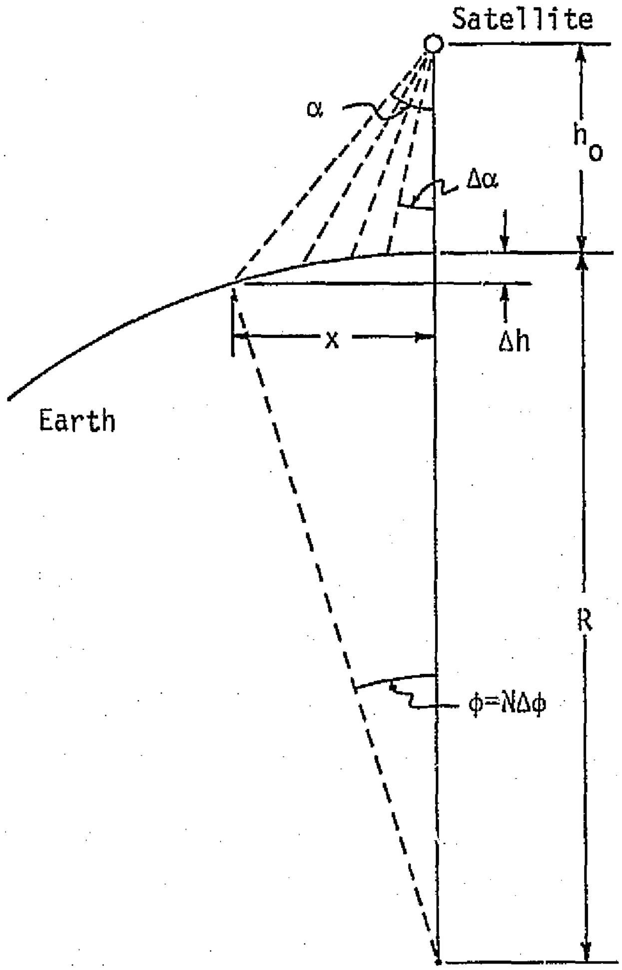


Figure A-3

θ = Latitude of satellite sub-point

$R' = R\cos\theta$

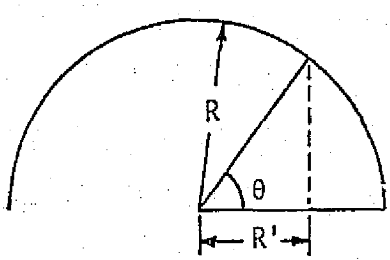
ε = angle between instantaneous intersection of the orbital plane and latitudinal plane.

$= \cos^{-1}(\cos Q/\cos\theta)$

$V = 2\,R\cos\theta/T$

$V_F = V\cos\varepsilon$

$V_S = V\sin\varepsilon$



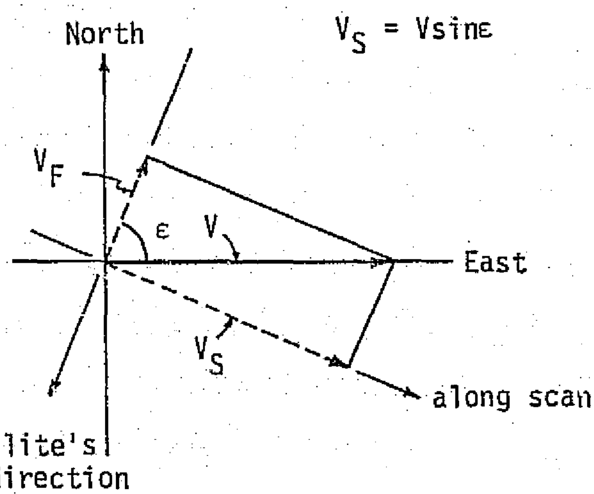


Figure A-4

where h_0 is the satellite altitude at the time of image acquisition.

The detector signals are sampled at uniform angular increments $\Delta\alpha$. Thus,

$$\alpha = I \, \Delta\alpha = I \, \frac{2\pi w}{S} \qquad \text{(A-2)}$$

where I is the original sample number counted from the center of the scan line. We want to resample the original data so that the new samples (indexed by N) represent the reflected energy at equidistant points along the ground track of the scan line. Since from figure A-2, it can be seen that the scanning is symmetric about the nadir, it is only necessary to derive the algorithm for one half of the line scan.

If D is the desired distance between samples then:

$$D = R \, \Delta\phi$$

and

$$\phi = N \, \Delta\phi = \frac{ND}{R}$$

From equations (A-1) and (A-2), we have:

$$I = \frac{S}{2\pi w} \cdot \tan^{-1} \frac{\sin(ND/R)}{\frac{h_0+R}{R} - \cos(ND/R)} \qquad \text{(A-3)}$$

We wish to select the horizontal spacing (D) between sample points to be equal to the vertical spacing (L) between lines. To determine L, we must take into account the forward motion of the satellite and the rotation of the Earth, as follows:

$L \stackrel{\Delta}{=}$ ground distance between scan lines in km

= (ground speed of forward motion)x(scan period)

= (ground speed due to satellite + ground speed due to Earth's rotation)x(scan period)

The ground speed of the satellite (V_o) is given by:

$$V_o = \frac{2\pi R}{P} \tag{A-4}$$

The three angles which are used to compute the components of the ground speed due to Earth motion are the orbital inclination angle Q, the latitude of the satellite sub-point θ, and the angle ε between an instantaneous orbital plane and a latitudinal plane. It can be shown that these angles are related by:

$$\cos \varepsilon = \frac{\cos Q}{\cos \theta} \tag{A-5}$$

Figure A-4 shows the two components of Earth rotational velocity (V), consisting of one along the scan (V_s), and another along the forward direction of motion (V_F). The magnitude of the rotational velocity is given by:

$$V = \frac{2\pi R \cos\phi}{T} \tag{A-6}$$

Thus, the ground speed due to Earth's rotation is:

$$\begin{aligned} V_F &= V \cos \varepsilon \\ &= \frac{2\pi R \cos \theta \cos \varepsilon}{T} \\ &= \frac{2\pi R \cos Q}{T} \end{aligned} \tag{A-7}$$

From (A-4) and (A-7), we can determine L:

$$\begin{aligned} L &= \left[\frac{2\pi R}{P} + \frac{2\pi R \cos Q}{T}\right] \frac{1}{W} \\ &= \frac{2 R}{W} \left(\frac{1}{P} + \frac{\cos Q}{T} \right) \end{aligned} \tag{A-8}$$

Letting D = L, by substituting (A-8) into (A-3) we have:

$$I = k \tan^{-1}\left[\frac{R \sin(N\Delta\phi)}{(h_o+R) - R\cos(N\Delta\phi)}\right] \tag{A-9}$$

where

$$k = \frac{S}{2\pi W}$$

$$\Delta\phi = \frac{2\pi}{W}\left(\frac{1}{P} + \frac{\cos Q}{T}\right)$$

$$N = 0, 1, 2, \ldots$$

For a given value of N, we compute I from equation (A-9). Since this I is not necessarily an integer, we compute the new radiometric sample N by linear interpolation between the original radiometric values of the integer sample numbers which bracket I.

Correction for Earth's Rotation

Because of the rotation of the Earth and the inclination of the satellite's orbit, the subsatellite point of every scan line of the radiometer is displaced westward. The amount of displacement depends on the latitude, inclination of the satellite orbit and the instananeous angle of intersection of orbital plane and the latitudinal plane. This effect introduces skew distortion in the resulting image.

Referring to figure A-4 and equations (A-5) and (A-6), we see that the drift velocity in the direction of the scanning motion is given by:

$$V_s = V \sin \varepsilon$$

$$= \frac{2\pi R \cos\theta \sin\varepsilon}{T}$$

$$= \frac{2\pi R(\cos^2\theta - \cos^2 Q)^{1/2}}{T}$$

From figure A-4 we see that $x = ND$ is the distance from the subsatellite point to the new sampling point N. The drift can be compensated for by adding the drift distance for m lines, $m\Delta x$, to the distance x if the new sampling point is on the right of the subsatellite point and subtracting it if it is on the left. Thus, equation (A-3) becomes:

$$I = \frac{s}{2\pi w} \tan^{-1} \left[\frac{\sin\left(\frac{ND \pm m \Delta x}{R}\right)}{\frac{h_o + R}{R} - \cos\left(\frac{ND \pm m \Delta x}{R}\right)} \right] . \tag{A-11}$$

substituting equations (A-8) and (A-10) into (A-11), we have:

$$I = k \tan^{-1} \frac{\sin(N \Delta \phi \pm m \Delta \beta)}{\frac{h_o + R}{R} - \cos(N \Delta \phi \pm m \Delta \beta)} \tag{A-12}$$

where

$$k = \frac{s}{2\pi w}$$

$$\Delta\phi = \frac{2\pi}{w} \left(\frac{1}{p} + \frac{\cos Q}{T}\right)$$

$$\Delta\beta = \frac{2\pi}{w} (\cos^2\theta - \cos^2 Q)^{1/2}$$

It can be shown that $m\Delta\beta$ is small compared to $N\Delta\phi$, and that I can be accurately approximated by the first two terms of its Taylor's series expansion:

$$I = k \tan^{-1} \left[\frac{\sin(N \Delta \phi)}{\frac{h_o + R}{R} - \cos(N \Delta \phi)} \right] \pm \frac{m\, k\, \Delta\beta \left[\left(\frac{h_o + R}{R}\right) \cos(N\Delta\phi) - 1 \right]}{\left(\frac{h_o + R}{R}\right)^2 - 2\left(\frac{h_o + R}{R}\right) \cos(N \Delta \phi) + 1} \tag{A-13}$$

where k, $\Delta\phi$, $\Delta\beta$, m, and N are defined above. Note that the sign of the second term on the right of equation (A-13) is positive if the new sample is

on the right side of the subsatellite point, otherwise it is negative.

Equation (A-13) serves as the basis for the algorithm for the correction of panoramic distortion and Earth rotation distortion. However, before it can be applied to an image, two parameters must be determined: the altitude of the satellite (h_0) and the latitude of the satellite sub-point (θ) at the time of image acquisition.

In early trials of the correction algorithm, we found that the algorithm was very sensitive to changes in the altitude of the satellite. It was necessary to use the altitude of the satellite at the time of image acquisition instead of using the nominal value for this parameter. Russell Koffler of NOAA-NESS supplied us with NOAA-4 orbital ephemeris data which gives the altitude at each minute during an orbit.

The latitude of the satellite sub-point at the time of image acquisition varies from day to day. We found that it was not adequate to use a nominal value for this parameter. In fact, this parameter varies during image acquisition, since the satellite is moving during the time the image is being sensed. However, we found that accurate distortion correction could be obtained by using a latitude value corresponding to the satellite location at the center of the image.

It is necessary to calculate the latitude from reference data in the image, as this information is not available from the ephemeris data. We have developed an algorithm for calculating this parameter which is based on a NOAA Technical Memorandum by Ruff and Gruber [A3].

We first select a reference point in the center of the original image which is easily detected in the image, and which has a known latitude (θ_r). In our work, we chose the intersection of the Middle Fork and the South Fork

of the Kings River as our reference point. We then determine the sample number (I_r) of this reference point in the image, measured from the center of the image, with positive to the left, or west on the image. The satellite nadir angle (α) for this reference point is given by:

$$\alpha = I_r \frac{2\pi W}{S} \tag{A-14}$$

the satellite zenith angle (z) is:

$$z = \sin^{-1}\left[\frac{R + h_o}{R} \sin \alpha\right] \tag{A-15}$$

From equations (A-14) and (A-15), we can calculate the geocentric viewing angle ϕ:

$$\phi = z - \alpha \tag{A-16}$$

the satellite latitude is then computed from the following expression:

$$\theta = \sin^{-1}\left[\frac{\sin \theta r - \cos Q \sin\phi}{\cos \phi}\right] \tag{A-17}$$

The reader is directed to the paper by Ruff and Gruber [A3] for the details of the derivations of these equations.

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A1: Schwalb, A. "Modified Version of the Improved TIROS Operational Satellite (ITOS D-G)", NOAA Technical Memorandum Ness 35. A United States Department of Commerce Publication.

A2: Legeckis, R. and John Pritchard, "Algorithm for Correcting the VHRR Imagery for Geometric Distortions Due to the Earth's Curvature and Rotation", NOAA Technical Memorandum NESS, Environmental Science Group, Washington, D.C., January 1976.

A3: Ruff, I. and A. Gruber, "Graphical Relations between a Satellite and a Point Viewed Perpendicular to the Satellite Velocity Vector (Side Scan)", NOAA Technical Memorandum NESS 65, Washington, D.C., March 1975

APPENDIX B

Least-Square Geometric Correction Algorithm

Images which have been geometrically corrected using deterministic algorithms such as is described in Appendix A will still contain residual distortions due to random errors or to deterministic errors which were not accounted for in the deterministic correction. In the second step of a geometric correction procedure, a least-squares transformation is applied to correct the residual errors. In the procedure which we employ, external reference information is used to characterize a bivariate polynomial image transformation which is used to transform the partially corrected image to the desired map projection.

Using image coordinates (x_i, y_i) and map coordinates (x_m, y_m), the transformation is the following:

$$x_i = a_o + a_1 x_m + a_2 Y_m + a_3 x_m^2 + a_4 y_m^2 + a_5 x_m y_m$$

$$y_i = b_o + b_1 x_m + b_2 y_m + b_3 x_m^2 + b_4 y_m^2 + b_5 x_m y_m$$

To determine the coefficients a_o, ..., a_5 and b_o, ..., b_5, locations of over 100 ground control points (GCPs) are determined on both the partially corrected image and on the appropriate USGS 1:250,000 scale maps. The coefficients are chosen to minimize the sum of the squared errors in the image coordinate system between the image GCPs and the transformed map GCPs.

The problem of calculating the coefficients can be seen to be a problem of multiple regression, and a variety of techniques are available for its solution. Let (x_{ij}, y_{ij}) be the coordinates of the j^{th} GCP in the image, and (x_{mj}, y_{mj}) be the corresponding coordinates in the map. Define the following parameters:

$$R_j = x_{ij}$$

$$Z_{1j} = x_{mj}$$

$$Z_{2j} = y_{mj}$$

$$Z_{3j} = x^2_{mj}$$

$$Z_{4j} = y^2_{mj}$$

$$Z_{5j} = x_{mj}\, y_{mj}$$

then subtract the arithmetic mean from each of these parameters:

$$r_j = (R_j - \overline{R}) \quad \text{where} \quad \overline{R} = \sum_{j=1}^{N} R_j$$

$$z_{kj} = (Z_{kj} - \overline{Z}_k) \text{ where} \quad \overline{Z}_k = \sum_{j=1}^{N} Z_{kj}$$

and where N is the number of GCPs.

The desired coefficients a_o, ..., as are given by the following:

$$\begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \\ a_5 \end{bmatrix} = \begin{bmatrix} T_{11} & T_{12} & T_{13} & T_{14} & T_{15} \\ T_{21} & T_{22} & T_{23} & T_{24} & T_{25} \\ T_{31} & T_{32} & T_{33} & T_{34} & T_{35} \\ T_{41} & T_{42} & T_{43} & T_{44} & T_{45} \\ T_{51} & T_{52} & T_{53} & T_{54} & T_{55} \end{bmatrix}^{-1} \begin{bmatrix} S_1 \\ S_2 \\ S_3 \\ S_4 \\ S_5 \end{bmatrix}$$

$$a_0 = \overline{R} - a_1 \overline{Z}_1 - a_2 \overline{Z}_2 - a_3 \overline{Z}_3 - a_4 \overline{Z}_4 - a_5 \overline{Z}_5$$

where $T_{k\ell} = \sum_{j=1}^{N} z_{kj} z_{\ell j}$

and $S_k = \sum_{j=1}^{N} r_j z_{kj}$

The equations for the coefficients $b_0, \ldots, b_5$ are very similar, and will not be given here.

For the image transformation to be correct, the locations of the GCPs must be determined very accurately and carefully. In order to do this, we display 256x256 sections of the 512x512 image on a video monitor and use a cursor to locate the GCPs. When we have located all of the points which are not under a cloud cover for that date, we compute the transform coefficients and transform the map GCPs to the partially corrected image. This allows us to observe the errors in GCP locations, and we then refine our image GCP locations if necessary. This avoids errors in GCP selection such as choosing the wrong feature in the image as the desired GCP. The transform coefficients are then recomputed.

This algorithm has been applied to images for four dates, and in each case, the coefficients for the square terms of the transformation were much smaller than those for the linear terms. This indicates that most of the highly nonlinear distortions have been removed by the deterministic correction algorithm.

Having now acquired the desired transformation, the positions of the output picture elements on the input image are determined. The image is then resampled, using the bilinear interpolation, in which the four neighboring input values are used to compute the output intensity by

two-dimensional interpolation. A discussion of the resampling procedure can be found elsewhere [B-1, B-2].

REFERENCES

B1: Van Wie, P., et al, "LANDSAT Digital Image Rectification System Preliminary Documentation", Information Extraction Division, Goddard Space Flight Center, Greenbelt, Maryland, Nov. 1975.

B2: Bernstein, R. And Ferneyhough, D. G., Jr., "Digital Image Processing", Photographic Engineering and Remote Sensing, Vol. 41, No. 12, Dec. 1975, pp. 1465-1476.

CHAPTER 3

WATER SUPPLY STUDIES BY THE BERKELEY CAMPUS RSRP GROUP

(Remote Sensing-Aided Procedures for Water Yield Estimation)

Co-Investigator: Siamak Khorram (Berkeley Campus)

Contributors: Edwin F. Katibah
Randall W. Thomas

CHAPTER 3

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WATER SUPPLY STUDIES BY THE BERKELEY CAMPUS RSRP GROUP
(Remote Sensing-Aided Procedures for Water Yield Estimation)

Co-Investigator: Siamak Khorram, Berkeley Campus
Contributors: Edwin Katibah
Randall Thomas

3.000 INTRODUCTION

During the present reporting period most of the work that has been performed by the Remote Sensing Research Program (RSRP) personnel at Berkeley Campus has continued to deal with water supply studies. The focus of these studies is on the development of remote sensing-aided procedures to provide cost-effective, timely, and satisfactorily accurate estimates of various important components of hydrologic models. Specifically, procedures are being developed for estimating the areal extent of snow, the water content of snow, the amount of solar radiation, and the loss of water to the atmosphere by evapotranspiration. The values obtained for these components by means of remote sensing will be used as inputs to each of the two state-of-the-art water yield forecast models currently being operated by the California Department of Water Resources (DWR). These are (1) the California Cooperative Snow Survey's (CSSS) model, and (2) the model of the federal-state River Forecast Center (RFC). The RSRP effort is being currently conducted in close coordination with that of other NASA Grant participants, particularly the efforts of the Algazi group on the Davis campus as described in Chapter 2 of this progress report. This cooperative effort involves an analysis of the sensitivity of the RFC runoff forecast model to its input components, particularly the model response that results from using a remote sensing-aided evapotranspiration estimate as one of the major input parameters.

This work, to be completed with the preparation of procedural manuals, describes the step-wise process which might best be followed by managers of water resources in using remote sensing as an aid to water resources inventory, development and management. Therefore, it is considered appropriate in this progress report to briefly summarize our findings to date relative to the preparation of procedural manuals. Most of the work that is about to be presented has been brought to completion during the present reporting period. As will presently be seen, however, that work is placed in proper context by first summarizing some of the work which our group has previously done, then describing our research activities during the present reporting period, and concluding with the first iterations of various procedural manuals that we

are in the process of preparing in order to maximize the prospect that water resource managers will effectively use remote sensing techniques of the type that we have been developing.

3.100 MATERIALS AND METHODS

The information contained in this section is divided into the three major phases with which our remote sensing research has dealt, each phase constituting a major input component to water yield forecast models. The phases deal with remote sensing-aided procedures for the estimation, respectively, of:

1) Snow areal extent
2) Snow water content, and
3) Evapotranspiration and solar radiation.

3.110 Summary with Respect to the Estimation of Snow Areal Extent

A different means of estimating areal extent of snow has been developed and tested by RSRP than is traditionally used. The RSRP method is based upon the analysis of Landsat color composite imagery divided into equal image sample units (ISU's). Two or more dates of Landsat color composite imagery are used for the analysis.

At the time of a Landsat overpass low altitude aerial photography is flown over randomly selected transects in the appropriate watershed. The image sample units as they appear on the Landsat imagery are transferred to the aerial photography. Estimates are then made of the percent of the ground that is snow-covered, based upon interpretation of the aerial photography in each ISU. Each such estimate is placed into one of five snow-cover condition-class categories used in this part of the study. Approximately one-half of the image sample units, as they appear on the aerial photography, are used in the training of the interpreter, the other half being used for testing of the interpretation.

The interpreter, thus armed, views the training image sample units on Landsat imagery of each pre-selected date. He uses the snow cover condition class estimates on the training ISU's (as interpreted on the aerial photography) to guide the training. Once trained, the photo interpreter then interprets the Landsat winter data (with the summer data superimposed), image sample unit-by-image sample unit, except for the training ISU's. Some of the image sample units that he interprets are those found on the supporting aerial photography. The interpreter's classification of these "testing " ISU's on the Landsat imagery is then statistically related to the snow cover condition class estimate on the "testing" ISU's found on the aerial photography. This is done by means of a ratio estimator statistic. This statistic is then used to

correct the interpreter's estimate of the areal extent of snow from Landsat data. The multistage sampling technique just described enables the researcher to establish the confidence intervals with a given probability (e.g. 95%) around the estimated values of the areal extent of snow.

3.120 Summary with Respect to the Estimation of Snow Water Content

Snow water content is estimated by integrating snow areal extent data, as described above, with ground measurements collected on several snow courses used by the California Department of Water Resources. This Landsat-aided snow water content estimation system utilizes a stratified double sample design.

In developing the procedure presently to be described, RSRP personnel selected three dates of Landsat imagery to provide conventional snow course measurement data. Over 2,200 image sample units were interpreted manually using analagous to that previously described for estimation of snow areal extent. The resulting information was then transformed into snow water content indices by a first order, time specific model. The watershed was classified into six unique strata to control the overall basin snow water content index.

A comparative cost-effectiveness analysis was conducted simultaneously with the interpretation and statistical work. Investigations with respect to cost focused on an analysis of the CCSS budget, an estimate of the cost of snow survey work within the Feather River Basin in 1974, and a determination of average costs for typical ground and image sample units. Parallel investigations with respect to effectiveness included an examination of the precision and accuracy of existing snow water content and water yield estimates.

The results obtained to date indicate substantial potential cost and/or precision advantages to be gained by use of conventional ground measurement snow course data integrated in a double sampling framework with Landsat-derived information.

3.130 Summary with Respect to the Estimation of Evapotranspiration

The problem of obtaining an estimate of evaporation from the soil throughout a given area is a very difficult one. In most instances, however, the problem is simplified by using representative point estimates in catchments (watersheds) or sub-catchments. If vegetation is present, the estimation of areal evapotranspiration (ET) is even more difficult because of the diversity of evaporating surfaces and the consequent need for a proportionally larger number of ET measuring points, which are often expensive to install and maintain. Judging from our work, as described below, the use of remote sensing techniques, combined with a limited number of appropriate ground measurements, can help solve some of the problems that are entailed in the estimation of evapotranspiration, area-by-area.

As will presently be seen, the remote sensing-aided system developed by our RSRP to estimate evapotranspiration is designed to give timely, relatively accurate, cost-effective evapotranspiration estimates on a watershed. The methodology is based on estimation of the major components that serve as inputs to ET estimation models (i.e., solar radiation, elevation, slope, temperature, etc.). We have tested the methodology in the Spanish Creek watershed which is a sub-basin of the Feather River watershed in the northern part of California's Sierra Nevada mountains. In this methodology, a multistage, multiphase sample design is utilized to estimate evapotranspiration losses, area-by-area, throughout the watershed. Basically, there are three increasingly resolved levels of data, each of which is sampled. The first level is composed of satellite and topographic data. Vegetation, terrain and meteorological types of information are defined for a convenient base resolution element, in this case a small group of Landsat pixels. Based on this information that is associated with each base resolution element, an estimate of evapotranspiration is made for that location. The appropriate ET equations, defined as Level I models, must be able to perform adequately on this "least resolved" information available from the first data level. Adequate performance is defined as a generation of ET estimates strongly correlated to actual ground-measured or ground-based estimates of evapotranspiration and to the runoff forecast analysis of the California-River Forecast hydrologic model after ET results have been used as one of the major inputs.

After an estimate of evapotranspiration has been made for each basin resolution element, the resolution elements (here 3 x 3, 4 x 4, or 5 x 5 blocks of pixels) are grouped into primary sampling units (PSU's). Within each PSU selected, a series of secondary sampling units (SSU's) is defined and photographed at large scale with light aircraft. At the SSU stage of sampling design, more specific information concerning local vegetation canopy, soil, and local climatic conditions is available as opposed to that obtainable from information at level one. Thus level two evapotranspiration models, employing more data types and more refined data, are used to generate evapotranspiration estimates for each PSU. A sample consisting of two of the SSU's per selected PSU, is then randomly chosen for further analysis on the ground. For each of these selected SSU's detailed ground measurements are made of vegetation canopy geometry, color, etc. as well as of soils and liter-organic debris conditions. The detailed information that is derived from this third level is then used to drive evapotranspiration prediction models. The full watershed estimate of evapotranspiration is developed by first using the ground based evapotranspiration estimate to calibrate the SSU estimate derived from photo data and then expanding the calibrated SSU estimates to the PSU stage by utilizing the SSU selection weights developed earlier. Finally, the PSU evapotranspiration estimates are expanded, each over the appropriate stratum and then to the entire watershed, by applying the PSU selection

weights (proportion of evapotranspiration in the given PSU relative to all other PSU's in the watershed) originally calculated. This sampling technique allows a confidence interval value to be associated with the estimates.

Level I ET models utilize the first level of information resolution and provide the first estimate of ET for the appropriate PSU's. Empirical and semiempirical formulas are applied in this level. These formulas are modified based on the measured values of evaporation data in the watershed of interest. The input for these models comes primarily from Landsat, environmental (meteorological) satellites, ground meteorological stations, and digital topographic data. The variables to be derived from these data for the above models are surface temperature (daily average, minimum, maximum), all solar radiation components, relative humidity, precipitation, and cloud cover (Khorram, 1974).

Solar radiation is a major input to both first and second level ET models. We have developed an accurate, site-specific, timely, and inexpensive methodology for estimation of net shortwave, net longwave, and net solar radiation. This technique is fully described in our May 1976 NASA Grant report.

The basis for the evapotranspiration models that are applied to the second level of information resolution is that of energy conservation, which is a proven law of thermodynamics. For this level, the energy-balance method is combined with other methods for consideration of vegetation canopy effects and advected energy processes. The objective of the model applied at Level II is to capitalize on vegetation canopy, geometry-composition, and other surface data available from aerial photography to provide improved evapotranspiration estimates for the appropriate photo SSU's (Khorram, 1974).

The third information resolution level in the remote sensing-aided evapotranspiration estimation system allows use to be made of both the simple and the more sophisticated models. The approach used requires one to select and develop those evapotranspiration estimation equations which are most rational and physical in terms of the actual processes involved. A combination of empirical, energy balance, and aerodynamic methods should be examined for this level.

3.200 CONTINUING RESEARCH SINCE MAY 1976

3.210 Snow Quantification

In previous progress reports prepared by personnel of our Remote Sensing Research Program, techniques were described for using remote sensing as an aid in estimating (1) areal extent of snow and (2) snow water content. (These techniques have been briefly summarized

in the preceding sections of the present report.) These two techniques togather comprise the snow quantification research that our group currently is completing. Because both of these techniques have demonstrated their ability to characterize efficiently the resource parameters which they were designed to estimate, procedural manuals are now being compiled for each technique.

Since application of the "areal extent of snow" technique is the first step in the snow water content estimation procedure, the two systems are linked through information and data gathering requirements. To help the potential user of such snow quantification systems, refinement of both techniques and the preparation of procedural manuals constituted the primary research objectives of our group for the May 1976 to May 1977 reporting period. It was determined that the most significant single improvement in areal extent of snow estimation (and hence in snow water content estimation) could be achieved by optimizing the basic estimation elements, i.e. the image sample units (ISU's).

The ISU's used for the previous research were approximately 2000 by 2000 meter blocks (400 hectares) laid out over the watershed being investigated. We arrived at this ISU size because it allowed enough samples to be taken from supporting low altitude aerial photography while minimizing the number of ISU's for the interpreter to analyze. This reduced the interpretation time and, thus, interpreter fatigue. While this ISU size provided the necessary analysis capabilities for achieving the ultimate research objectives, it was realized that at least two advantages could be gained from "optimized" ISU size.

The first improvement would be reduced sample variance. The hypothetical relationship between ISU size and sample variance is illustrated in Figure 1.

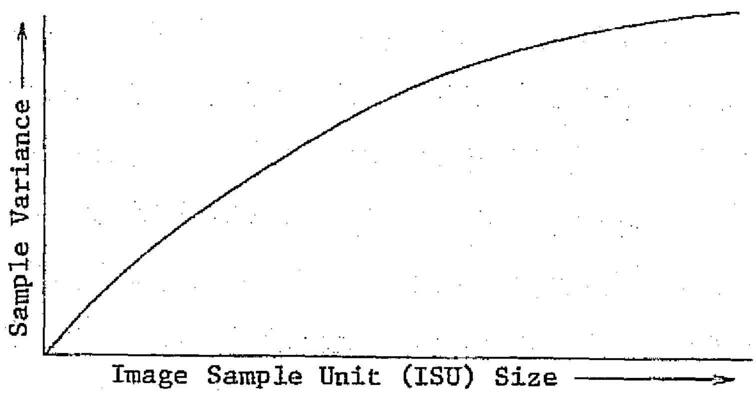

Figure 1. Hypothetical relationship between image sample unit (ISU) size and sample variance

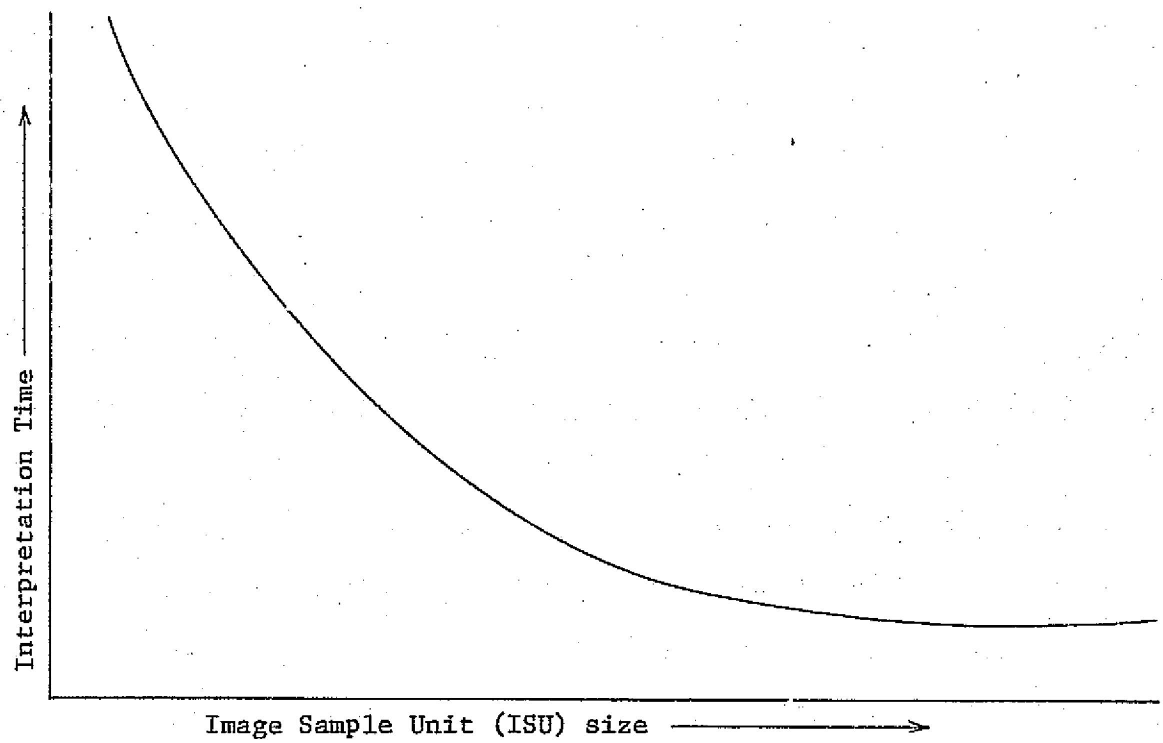

Figure 2. Hypothetical relationship between Image Sample Unit (ISU) size and interpretation time.

Thus, if the image sample size were reduced, the sample variance would be reduced also, (Figure 1), but the interpretation time (and interpreter fatigue and thus inaccuracy) would be increased (Figure 2).

If, in view of these "trade-offs", we could optimize the variance and interpretation time with respect to one another, our techniques for estimating the areal extent of snow and snow water content would be expected to improve in terms of both estimation accuracy and speed of operation. Consequently the final result of this research could be expected to be an optimization of both variance and time consideration as seen in Figure 3.

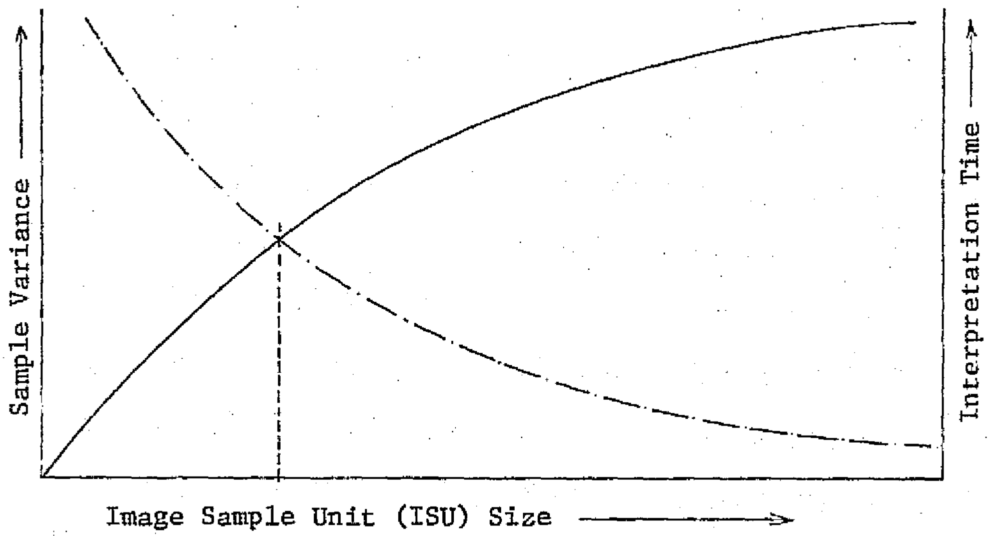

Figure 3. Hypothetical determination of optimal variance/versus interpretation time per image sample unit size.

To calculate the actual curves for ISU size versus sample variance, and ISU size versus interpretation time, three dates in the winter of 1973 were chosen (April 4, May 10 and May 27) and three ISU sizes (100,255 and 400 hectares, respectively) for each date were also selected. The analysis procedure that was used followed that used previously in estimating the areal extent of snow as described in our May 1976 Annual Progress Report. Accurate accounting of both interpretation time and sample variance was obtained for each ISU size on each date of analysis to facilitate the optimization procedure.

3.220 Evapotranspiration

The methodology developed by the Remote Sensing Research Program for evapotranspiration estimation utilizes some watershed physiographic data as well as data with respect to climatic variables. The physiographic data consists of vegetation type, ground cover, and elevation. The climatic data consists of temperature, humidity, wind, precipitation, solar radiation, and a few standard meteorological constants. The specific climatic data required for use in ET models varies with the level of modeling. Level I ET models use solar radiation, temperature, humidity, and precipitation as the main variables. Level II and III ET models utilize the required input variables for Level I as well as a psychrometric constant, the ratio of saturation vapor pressure to temperature, canopy resistance, aerodynamic resistance, and atmospheric conductance. All ET models and their required input data are described in the May 1976 NASA Grant report.

Solar radiation is one of the major input components for all three levels of ET models and is the ultimate source of the earth's energy as well as being the driving force for all of the hydrological processes. Therefore, the ability to better estimate solar radiation could produce significant improvements in our ability for site specific estimation of both water supply and vegetation water demand (consumptive use). The RSRP group has developed a remote sensing-aided technique and model for estimating solar radiation. The climatic input variables to the model include temperature, cloud cover and albedo. The estimates are site-specific as a function of slope, aspect, latitude, day length, elevation, and vegetation type. Based on such information a net solar radiation map has been produced of the Spanish Creek Watershed. The primary results are in general agreement with values reported in the literature for similar areas in the same latitude but are, of course, more specific in terms of site, time and accuracy.

Some of the evapotranspiration estimation models have been tested in the previously mentioned Spanish Creek Watershed (SCW). The physiographic characteristics of the SCW have been determined and the areal distribution of input parameters for both solar radiation and Level I ET models have been documented. As an example, the watershed-wide map of water loss to the atmosphere (evapotranspiration) for the

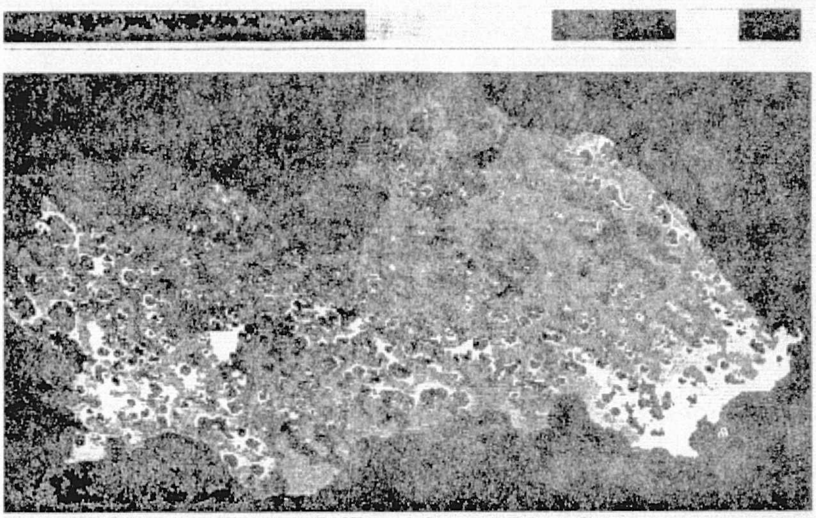

Figure 4. Areal distribution of daily potential evapotranspiration estimates in inches for August 14, 1972, over the Spanish Creek Watershed, based on the Jensen and Haise equation.

Red = 0.1 - 0.28	Green = 0.31
Orange = 0.28	Green blue = 0.31
Yellow = 0.29	Blue Green = 0.32
Brown = 0.30	Blue = 0.33 - 0.38

SCW is shown in Figure 4. This ET map is based on the Jensen and Haise model (Khorram 1975).

Performance evaluation of ET models could be obtained by two means: 1) by comparing results obtained when using the models with corresponding measured values of actual and/or potential evapotranspiration made on the ground; and 2) by evaluating the results from runoff forecast models as obtained when remote sensing-aided estimates of ET were used as a direct input. In our research, because of the lack of measured evapotranspiration data on the ground, the second method is being used for evaluating the results and the California River Forecast Center (RFC) hydrologic model (sometimes referred to as the Sacramento Model) is being used for this evaluation. This study is being carried on in coordination with U.C. Davis (Algazi) group. As explained in Chapter 2, that group has been involved for several years with the sensitivity analysis of RFC models not for the Spanish Creek Watershed, but for the Middle Fork of the Feather River Watershed (MFFR). Consequently, it became apparent that, in order to maximize the integration between our research efforts and those of the U.C. Davis group, all of our evapotranspiration models that had been developed for the Spanish Creek Watershed should be reapplied to the Middle fork of the Feather River. This has lead to two problems: 1) determining the physiographic characteristics of the MFFR watershed; and 2) collecting the necessary input climatic data for that watershed. Much of the RSRP evapotranspiration research in the last few months has involved working on reapplication of the methodology developed for the Spanish Creek Watershed for our new watershed.

The new watershed (MFFR) is much larger than the old one, with greater diversity in vegetation type, elevation differences, and slope and aspect. The boundaries of both the Middle Fork and Spanish Creek watersheds and their locations with reference to the entire Feather River Watershed are shown in Figure 5 .

3.221 Climatic Data Collection for ET Models

Climatic data required for use in the remote sensing-aided evapotranspiration estimation system is not fully available within the watershed covering the Middle Fork of the Feather River. The number of meteorological stations in this catchment is limited. Also, data pertaining to only a few types of climatic parameters has been taken at each station. A similar problem existed within the Spanish Creek Watershed, and the personnel of the Remote Sensing Research Program, with the cooperation of several U.S. Forest Service employees working on the Plumas National Forest, collected additional climatic data for that area. This data was composed of "Weather Bureau Class A" evaporation pan data and evaporimeter data. Evaporimeters were designed by RSRP personnel

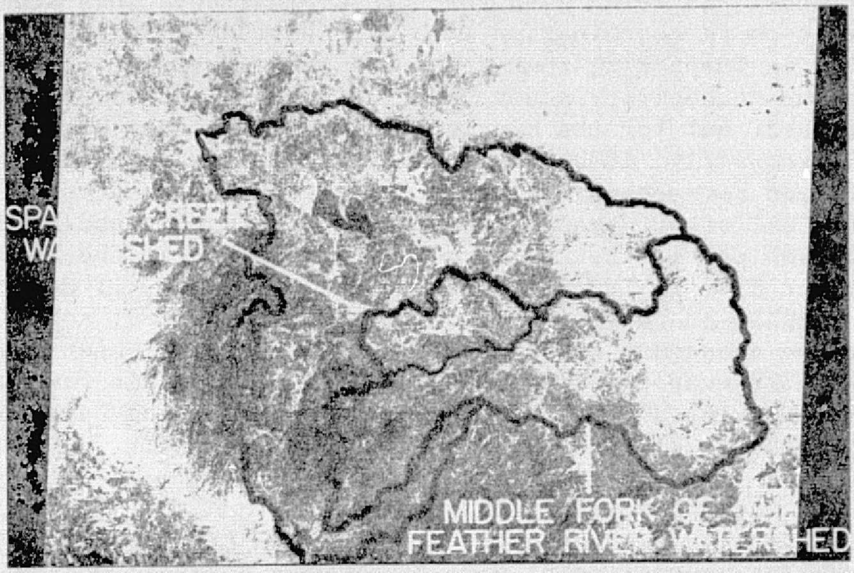

Figure 5. Boundary limits of Spanish Creek Watershed (old one), Feather River Watershed, and the watershed covering middle fork of Feather River (new one).

with the cooperation of the California Department of Water Resources at Red Bluff. Both the evaporation pan and the evaporimeter data are collected simultaneously. This additional data was collected at each of 4 localities on the Plumas National Forest, viz. Mohawk, Mount Hough, Quincy, and the U.C. Forestry summer camp at Meadow Valley.

Since the date for application of ET models for the new watershed (MFFR) is 1975, to correspond to the analysis date of the RFC hydrologic model by the Algazi group at U.C. Davis), there cannot at this late date be any pan evaporation and evaporimeter data collected for this new watershed. According to the sensitivity analysis of the RFC model by the U.C. Davis group, the runoff variation is most sensitive to evapotranspiration in the springtime. Therefore, the spring of 1975 will be the first candidate time during which to incorporate ET information into our water yield forecast model. This eliminates the use of some of the climatic data collected by the Forest Service ranger stations during the fire season (middle of May to middle of October).

Within the MFFR there are only 14 meteorological stations which are listed in Table 1 . The data types collected in these stations include temperature (dry bulb, wet bulb, max., min.), humidity, wind, precipitation, and cloud cover.

This data is collected by USDC Environmental Data Service (National Climatic Center), Plumas National Forest, and the California Department of Water Resources. Table 2 . summarizes all the data sources, including data type, used in ET models.

3.222 Physiographic Characterization of the Middle Fork of Feather River Watershed

In order to use remote sensing to maximum advantage in characterizing the physiography of each portion of the watershed covering the Middle Fork of the Feather River a 3-step process was required:

1. Geometric correction of Landsat data

2. Boundary determination of the watershed

3. Vegetation/terrain and topographic analysis of the watershed

The vegetation/terrain analysis is dependent partially on the watershed boundary determination, which is in turn almost fully dependent on the geometric correction of Landsat data. The geometric correction of the Landsat data is, of course, necessary for other phases of the evapotranspiration estimation procedure beyond the scope of physiographic characterization. The watershed boundary determination

Table 1. Existing ground meteorological stations within and around the watershed covering the Middle Fork of the Feather River.

Station Name	Latitude (N)	Longitude (W)	Elevation (Feet)
Brush Creek	39°41'	121°21'	3560
Bucks Creek Pump House Challenge	39°55'	121°20'	1760
Forbestown			2900
Greenville Ranger Station	40°08'	120°56'	3560
Mohawk Ranger Station	39°47'	120°38'	4370
Oroville Ranger Station	39°32'	121°34'	300
Plumas Creek State Park	39°45'	120°42'	5165
Portola	39°48'	120°28'	4850
Quincy	39°55'	120°57'	3408
Sagehen Creek	39°26'	120°14'	6337
Sierra City	39°34'	120°38'	4150
Sierraville Ranger Stations	39°45'	120°22'	4975
Vinton	39°49'	120°11'	4950
Woodleaf Oroleve	39°31'	121°11'	3340

Table 2. Available Ground Meteorological Station Data Within the Middle Fork of the Feather River Watershed for 1975

Meteorological Stations	Temperature (F°)	Precipitation	Relative Humidity
Brush Creek		yes	
Bucks Creek Pump House		yes	
Challenge Ranger Station	yes	yes	yes
Forbestown	yes	yes	
Greenville Ranger Station		yes	yes
Mohawk Ranger Station	yes	yes	
Oroville Ranger Station	yes	yes	yes
Plumas Creek Ranger Station	yes	yes	
Portola	yes	yes	
Quincy	yes	yes	yes
Sagehen Creek		yes	
Sierra City	yes	yes	
Sierraville Ranger Station	yes	yes	
Vinton	yes	yes	
Woodleaf Oroleve		yes	

is necessary in this, and other phases of the evapotranspiration research (1) to reduce computer time in analysis procedures, (2) to provide an accurate summary of the data specific to each parameter of interest, and (3) to provide a meaningful visual presentation of the results. The vegetation/terrain analysis is being used as a basis for albedo mapping of the watershed. Albedo is one of the important input parameters for solar radiation estimation.

Geometric Correction of Landsat Digital Data

The Landsat digital data, as we received it from the EROS data center, contained a certain amount of spatial distortion as compared with map projections commonly in use. In order to rectify this data, it was necessary to lay out a network of geometric controls over the specific Landsat scenes. A transformation equation was then generated to convert the Landsat data to its planimetric position. This geometric rectification of Landsat digital data is a necessary step to facilitate further analysis and to enhance the appearance of visual results.

Much of the topographic data used in this evapotranspiration research is derived from United States Geological Survey Topographic Series maps, based on the transverse mercator projection system. This data includes elevation, slope, aspect, and watershed boundaries. Other necessary data, such as location of the ground meteorological stations within and around the watershed, must be determined. Watershed-wide distribution of data collected at these stations must be comparable (location-wise) to the Landsat digital data and its manipulations. The final products of the research effort must all be of common appearance, as far as the boundary of the research area is concerned. This makes it necessary to correct the Landsat data to the map projections used by the other data sources, in this case the transverse mercator projection system.

A total of 35 control points were located in and around the Middle Fork of the Feather River Watershed. These points were related directly to river courses or water bodies. Control points located along river courses were located at major river/stream intersections and on bends in the rivers. Dams on lakes and reservoirs provided for the most accurate control point location available due to the almost vertical displacement of apparent lake (or reservoir) shorelines. Control points were located both on the Landsat digital data and on U.S. Geological Survey 1:250,000 topographic series maps. These control points were first located on the topographic maps. Then they were identified on the Landsat digital data, and displayed in a simulated infrared color enhancement form on a color television monitor. A variable x, y cursor

on the color television monitor allowed each control point to be identified in terms of its nearest Landsat picture element (pixel). Location of the control points used for this study is shown in Figure 6 . The control points based on the U.S.G.S. topographic maps were digitized to provide their coordinate information. This coordinate system was then statistically related to the x, y coordinate values for the control points as located on the Landsat digital data. A linear regression model was then generated to give the transformation equation necessary to geometrically relocate the Landsat digital data to the transverse mercator map projection data.

Boundary Determination of the Watershed (MFFR)

Determination of the watershed boundary on the Landsat digital data is necessary to:

1. Accurately determine the water input and output for the watershed
2. Minimize computer expenses by keeping the area that is to be analyzed to the smallest possible dimensions.
3. Provide an accurate and meaningful summation of computer generated data for the watershed.
4. Provide useful visual presentation and hardcopy of the results.

The location of the watershed boundary is done in conjunction with the geometric transformation of the Landsat digital data. The watershed boundary is carefully determined and annotated on the same U.S.G.S. 1:120,000 topographic series maps as are used in locating the control points. The watershed boundary is digitized at the same time as the control points. This gives a geometric description of the watershed boundary relative to the control points (see Figure 6).

The digitized boundary can now be incorporated to the Landsat digital data using the transformation equation previously generated.

Vegetation/Terrain Analysis of the Watershed

Knowledge of the spatial distribution of vegetation/terrain features in the Middle Fork of the Feather River Watershed is necessary for generation of albedo indices. Albedo is used directly as an input to the short wave radiation model, which ultimately is used in the watershed-wide calculation of evapotranspiration.

Approximately sixteen categories of vegetation/terrain features will be used in the final classification. The following categories represent the current vegetation/terrain types under consideration:

Red fir forest
Mixed conifer forest
Eastside timberland-chaparral complex
Mixed hardwood forest

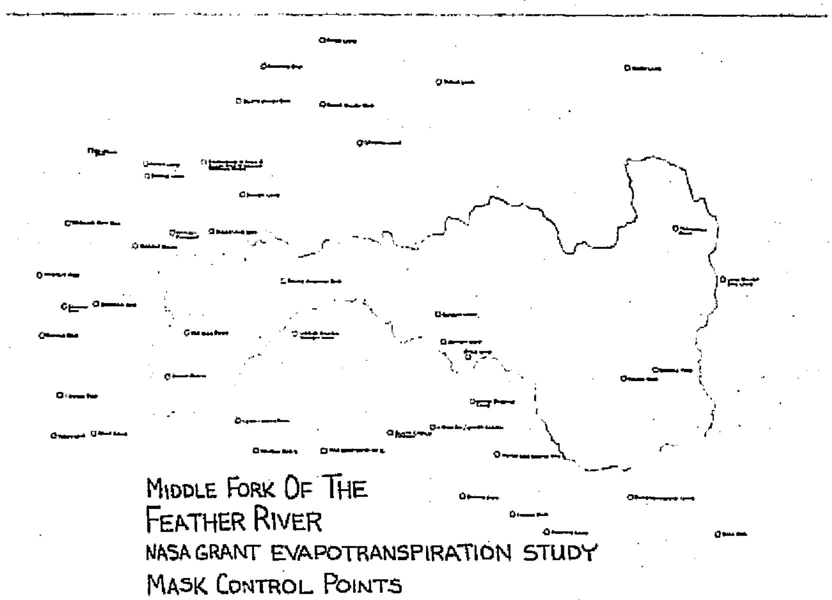

Figure 6. Boundary limits and location of control points within the watershed covering middle fork of Feather River.

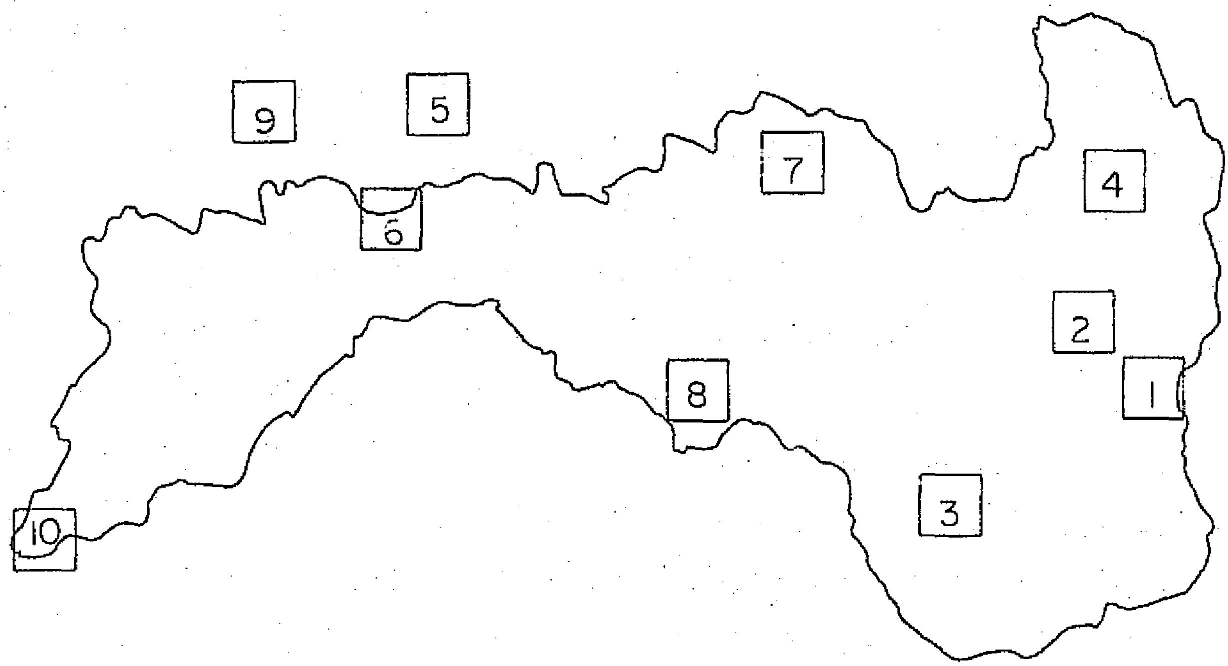

Figure 7. Distribution of Landsat test sites throughout the Middle Fork of the Feather River Watershed and surrounding area.

Area 1	Sierra Valley Mountains
Area 2	Sierra Valley Area 1
Area 3	Sierra Valley Area 2
Area 4	Franchman Reservoir Area
Area 5	Quincy/American Valley
Area 6	Serpentine Area
Area 7	Davis Lake Area
Area 8	Gold Lake Area
Area 9	Silver Lake Area
Area 10	Middle Forke/Lake Oroville

Riparian hardwoods
Foothill pine-oak woodland
Brush-chaparral complex
Sagebrush
Grassland-meadow
Marshland
Agriculture/rangeland
Water
Urban
Exposed soil
Exposed bedrock
Serpentine-vegetation complex

In order to determine how closely these vegetation/terrain types could be identified on the Landsat digital data, ten test sites were selected in and around the Middle Fork of the Feather River Watershed. These sites were selected from 1:120,000 scale high altitude aerial photography of the watershed area, as acquired by the NASA Earth Resources Program. Each of these sites is approximately 10,000 acres in size (100 x 100 Landsat picture elements). The sites are distributed throughout the watershed as shown in Figure 7 . All the test sites were identified on the Landsat digital data, and on 1:30,000 to 1:120,000 scale infrared ektachrome aerial photography. A computer compatible tape of the ten sites was made from the Landsat digital data. The ten 100 x 100 pixel sites on the computer compatible test were clustered according to an algorithm in a computer program known as ISOCLAS.

ISOCLAS performs a modified version of the clustering algorithm known as ISODATA to multispectral scanner data. The acronym ISODATA stands for Iterative Self-Organizing Data Analysis Technique (A). As its name imples, the algorithm is arrived at through an iterative procedure which groups similar "objects" into sets called clusters. The algorithm was originally developed by Hall and Ball (1965 and 1967) of the Stanford Research Institute. A clustering technique based on ISODATA and suitable for use in processing multispectral scanner data was developed by Kan and Holley (1972). To distinguish between the original and revised programs, the multispectral scanner version became known as ISOCLAS.

This procedure will, ideally, separate all of the data into distinct groups or clusters, the center of each cluster being represented by its mean. The process is initiated by assigning each data point to the nearest estimated cluster center (absolute distance is calculated to each cluster mean). After all of the data has been assigned, new means are calculated and tests are made to see if clusters should be split or combined. A cluster is split if the standard deviation of the cluster exceeds a specific threshold value. Two clusters are combined if the distance between cluster centers is smaller than the specified threshold. A cluster is deleted if it has fewer than some specified number of points. The data is reassigned, after each split or combining

iteration, to the new clusters and the process continues until the desired number of iterations has been obtained.

Since ISOCLAS is used in this case as a training device for the watershed-wide image classification of vegetation and terrain features, two approaches were evaluated on the initial ISOCLAS runs. In the first approach, all ten test sites were considered to be a portion of the same population of picture element reflectance values. The program was instructed to go through twelve iterations to reach no more than forty separate clusters. In this algorithm, the same minimum distance was sought between the cluster means. Also the same maximum (threshold) standard deviation was sought among the picture element reflectance values that makes up each cluster. Consequently, clusters found in one test could be absolutely related to clusters found in other test sites without any intermediate statistical manipulation. The advanrage of using this technique relies on the established statistical relationship between clusters in each test site. Instructions to the image classification program, which will ultimately analyze the watershed for vegetation/terrain classes, are relatively simple and straightforward. Similar (but not exactly the same) vegetation/terrain groups, easily identified on the aerial photography, were grouped into single clusters, due to the limitations of the number of classes available in the program. Although only fifty clusters are possible using this technique, it was estimated that approximately one hundred clusters would be needed to adequately characterize the entire range of vegetation/terrain classes found in the watershed when all test sites were analyzed in this fashion. A still more detailed classification might have been desirable, but was considered to be out of the scope of this project.

In order to minimize the restrictions which the ISOCLAS routine placed on the absolute number of clusters available, each test site was analyzed independently. The ISOCLAS program was again instructed to consider twelve iterations of no more than forty classes. However, using this approach it was possible to have up to forty clusters for each test site. It was found that, while not perfect, this technique represented the desired vegetation/terrain classes much more accurately than in the previous technique. Confusion in vegetation/terrain classes still existed, however, but generally in features with similar reflectance values. The fact that some vegetation/terrain classes were confused in the ISOCLAS clusters even though they were distinct on the aerial photography, probably can be attributed to the differences in texture of different features. This texture consideration is a function to which the ISOCLAS analysis is not sensitive.

One of the test site blocks taken on September 9 , 1975 , in color infrared small scale aerial photography (original scale, 1:120,000) is shown in Figure 8 . This site, located on the eastern edge of the

Middle Fork of the Feather River Watershed in the Sierra Valley region, is composed of the following six vegetation/terrain classes:

1. Bare soil
2. High density eastside conifer
3. Low density eastside conifer
4. Brush/chaparral
5. Sagebrush
6. Sagebrush/bare soil

The Landsat raw data display of the same area for August 13, 1972, is shown in Figure 9 . Both images are spectrally similar due to the season in which both were acquired and also due to the similar spectral rendition of each. Some banding can be observed due to improper functioning of the four sensors scanning six bands.

The ISOCLAS routine was instructed to differentiate amongst up to forty clusters for this test site. However, the natural appearance of the picture element values for this site limited the area to nineteen "natural" clusters. Two of these clusters were from within an area that was affected by a bad data line introduced by the ISOCLAS program, thereby leaving only seventeen clusters. These seventeen clusters appear to represent the vegetation/terrain classes found on the aerial photography fairly well, with no major confusion classes. Displaying the ISOCLAS results in such a way so that the clusters are easily interpreted presents a minor problem. The ISOCLAS clusters, each represented by a different color, are shown in Figure 10 . Organizing the clusters so that they will represent actual, visible ground vegetation/terrain classes is difficult when this type of display is used. In order to diaplay the ISOCLAS clusters in a more meaningful manner, ratios of the Band 7-to-Band 5 reflection mean values of each cluster were determined. These values were then ranked and a color was assigned to each value (Clark 1946). The ratioing method is based on the fact that vegetation in various forms and in different conditions (especially in the healthy condition) reflects relatively large amounts of near-infrared (Band 7) energy compared to visible red wavelength (Band 5) energy. Thus, the higher Band 7/Band 5 ratios are likely to indicate vegetation. Of course different plant species have different Band 7/Band 5 ratios; therefore, it was found possible to assign spectrally ordered colors to the numerically ranked Band 7/Band 5 ratios. Other terrain features, such as bare soil, bare ground, and water tend to have their own unique ratios, thus making it relatively easy to identify them. Table I is a listing of the nineteen clusters found in this test site with their associated Band 7/Band 5 ranked mean ratio values and the corresponding assigned colors. The Band 7/Band 5 ratio-ranked display presents a more meaningful representation of the ISOCLAS clusters than the display utilizing the random assignment of colors to the clusters (see Figure 11).

Figure 8. Small scale aerial photographs of ISOCLAS block 1 taken by U2 aircraft on September 9, 1975.

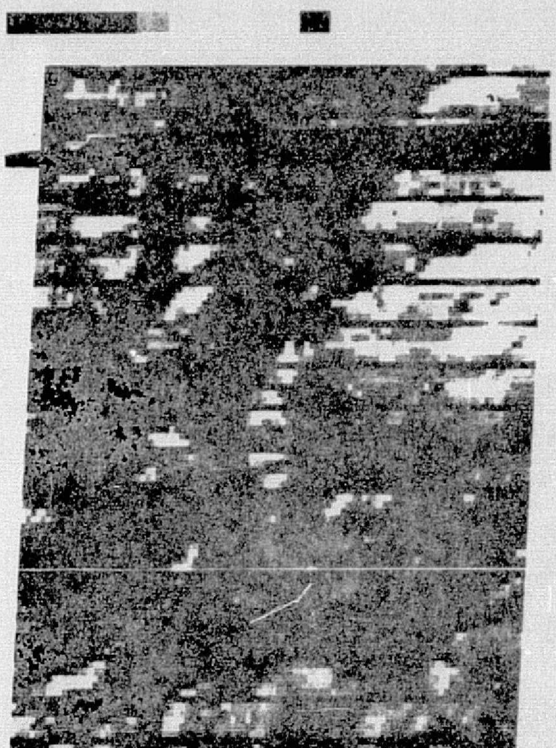

Figure 9. Raw data digital display of ISOCLAS block 1 based on Landsat data including bands 4, 5 and 7.

Figure 10. Default display of ISOCLAS block 1 based on Landsat data.

ISOCLAS 7/5 RATIO, BLOCK 1

Figure 11. Band 7 to band 5 ratio display of ISOCLAS block 1 based on Landsat data.

Figure 12. Classified ISOCLAS display of block 1 based on Landsat data. All the classes are described in Table 3.

Table 3. List of 7/5 ratios and clusters identified on type ISOCLAS block 1 for each vegetation-terrain.

Vegetation/Terrain Class	Cluster	Band 7/Band 5 Ratio
High density eastside conifer	5 7	2.4534 2.1284
Low density easiside conifer	9	2.0276
Brush/Chaparral	10	1.5688
Sagebrush/Bare Soil	12	1.6127
	2	1.1484
	4	1.1032
	8	1.1236
	16	1.1812
Sagebrush	1	1.2037
	3	1.3381
	6	1.1751
Bare Soil	11	1.0396
	13	1.0960
	14	1.0844
	15	1.0592

The final assignment of specific ISOCLAS clusters to vegetation/terrain classes is the result of associating the Band 7/Band 5 ratio television display results with the high altitude aerial photography and the computer print out of the ISOCLAS clusters. Specifically, areas represented on the 7/5 ratio display which can be accurately identified on the aerial photography as a specific vegetation/terrain class, are located on the computer printout. The computer printout is organized on an x and y format with a separate character representing each cluster. All clusters found within the area identified from the coordinates are then placed within the vegetation/terrain class previously identified. This procedure is done until all clusters have been assigned to a specific vegetation/terrain class. The result of this cluster classification of the ISOCLAS results can be seen in Figure 10. Table 3 lists the 7/5 ratios and clusters for each vegetation/terrain type identified in the ISOCLAS block "1" test site.

By use of the analysis method shown in Table 4, it is possible to facilitate the identification of vegetation/terrain classes in which some classification confusion exists.

The ISOCLAS statistical summaries for each cluster form the basis for the training of a classification routine which will ultimately place every picture element into its predetermined vegetation/terrain class. While the 7/5 ratio method provides useful information for cluster distribution, it cannot be expected to decide, statistically, to group clusters into vegetation/terrain classes. The development of a method for measuring class (or cluster), separability is extremely important due to the individual clustering performed by ISOCLAS on each of the ten test sites. A methology for the determination of class separability based on Scheffe has been applied to this analysis. Statistical analysis using Scheffe 1959 method allows significance probabilities to be calculated for all cluster pairs. These probabilities are displayed in matrix form. Class pairs with significance probabilities below specific threshold values are considered to be separable for classification purposes. Thus individual clusters can be statistically compared to other clusters within a given test site and all other clusters in the remaining nine test areas.

Clusters determined not to be separable by this technique are combined. If the various components comprising a group of clusters are found to be inseparable from one another, while representing a number of different vegetation/terrain classes, stratification of the entire population of picture elements (the Middle Fork of the Feather River, in this case) on the basis of major vegetation/terrain features may be necessary. Regardless of the outcome of the Scheffe based class separability tests, the statistical summaries for each separable cluster or cluster-group are used to train the classification routine used at RSRP called CALSCAN.

Table 4. Band 7/Band 5 ratios and color assignments for ISOCLAS block 1

Band 7/Band 5 Ratio*	Numerical Order	Cluster	Color Assignment Group
2.4534	1	5	Lavenders & Reds
2.1284	2	7	
2.0276	3	9	
1.6127	4	12	
1.5688	5	10	Browns & Oranges
1.3381	6	3	
1.2037	7	1	
1.1812	8	16	
1.1751	9	17	Yellows
1.1751	10	6	
1.1484	11	2	
1.1236	12	8	Greens
1.1032	13	4	
1.0960	14	13	
1.0844	15	14	Blues
1.0592	16	15	
1.0396	17	11	
-----	18	--	Black
-----	19	--	

*The actual equation for the Band/7/Band 5 ratio is:

2 x (Band 7 mean scene brightness value of cluster n) ÷ (Band 5 mean of scene brightness value of cluster n) where n goes from 1 to 17 inclusive.

CALSCAN is a maximum likelihood classifier based on the Purdue University image classification program, LARSYSAA. The CALSCAN program utilizes the IFOCLAS cluster training statistics to classify each picture element within the available population into a specific vegetation/terrain class.

The vegetation/terrain classification performed by the maximum likelihood classifier can be converted into areal distribution of albedo using a technique documented in our portion of the May 1975 Grant Report (Khorram 1975). The albedo calculation can then be used in a shortwave radiation model, necessary for the calculating of evapotranspiration in the Middle Fork of the Feather River Watershed. This method utilizes data obtained through conventional ground measurement of snow courses integrated into a double sampling framework with Landsat-derived data. Further investigation on optimizing image sample unit size and automatic analysis is expected to improve the precision of the snow water content estimates over the watershed.

Level I and II evapotranspiration estimation models have been developed. Level I models are based on first information level and utilize solar radiation, temperature, and humidity as the main input variables. Level II models are based on energy-balance and Level III models are based on energy-balance, together with aerodynamic and canopy resistances. Level I ET models have been applied to the Spanish Creek Watershed with satisfactory results. The results of ET models can be directly applied to the operational hydrologic model (inown as Federal-State River Forecase Center Model) used by the California Department of Water Resources. Comparison of simulated runoff values after and before the ET results have been used as an input in order to provide the information necessary for evaluation of ET models.

Based on our coordination with U.C. Davis NASA Grant participants, the Middle Fork of the Feather River Watershed was chosen as a test area and the spring of 1975 was chosen as the period for which data would be tested there. Currently, RSRP personnel are applying to this new watershed as described above.

3.300 SUMMARY/CONCLUSION

The methodology that has been developed by personnel of our RSRP for a remote sensing-aided system to estimate the various components of a water yield model will give timely, relatively accurate, and cost-effective estimates over snow-covered areas on a watershed-by-watershed basis. These components are snow areal extent, snow water content, water loss to the atmosphere (evapotranspiration) and solar radiation. The system employs a basic two stage, two phase sample of three information resolution levels to estimate the quantity of the above-mentioned components

of the water-yield model. The input data for this system requiring spatial information is provided by Landsat, by environmental (meteorological) satellites, by high and low flight aerial photography, and by ground observation.

The general concept of multistage sampling has been used successfully by RSRP in several other remote sensing research experiments involving manual and automatic data analysis. The design of this project facilitates the performance of valid statistical analyses. This is extremely important so that future results from different approaches can be analyzed with respect to one another and to prior research. Confidence intervals have been applied to all estimates discussed herein, thus providing figures relative to the accuracy of results.

Sources of input data for RSRP research on water resources include the entire spectrum of environmental data gathering systems currently operating. Satellite information sources include Landsat and NOAA. The primary photographic data base consists of large to medium scale photography obtained by our group. Ground data is collected with the cooperation of both federal and state agencies such as U.S. Geological Survey, National Climatic Center, U.S. Forest Service, California Division of Forestry, and California Department of Water Resources.

In the case of snow areal extent estimation, we have completed the manual analysis. One of the advantages of our technique versus conventional methods is that ours not only corrects the interpreter's snow areal extent classification to plot/ground values based on testing results, but also minimizes variation in final classification results between interpreters. Thus, a consistent result can be expected even though areal extent of snow estimation is performed on different areas by different interpreters. Also, the double sampling method, which in effect calibrates the more coarsely resolved Landsat based estimates, provides a good data bank for more accurate estimation of parameters of interest.

Judging from the results obtained when using the remote sensing-based techniques described above, it can be concluded that there is a substantial advantage in terms of both cost-effectiveness and precision to be gained through their use, as compared to other, conventional methods. Further investigations in automatic analysis of the areal extent of snow as well as further refinement of the corresponding manual interpretation technique are needed, in order to allow the user to make an intelligent choice as to the level of sophistication that he desires or can affort. The preliminary procedural manual for a remote sensing-aided system for snow areal extent estimation is described in Appendix I.

From the results obtained in our snow water content study to date, it can be shown that a potential cost and/or precision advantage is to be gained in this area, by also, by use of remote sensing-aided methodology. Our method utilizes data obtained through conventional ground measurement of snow courses integrated into a double sampling framework with Landsat-derived data. Further investigations on optimizing image sample unit size and on the use of automatic analysis techniques probably would improve the precision of the snow water content estimates.

Level I and Level II evapotranspiration estimation models have been developed. Level I models are based on the first information level and utilize solar radiation, temperature, and humidity as the main input variables. Level II models are based on energy-balance and Level III models are based on energy-balance, and on aerodynamic and canopy resistances. Level I ET models have been applied to the Spanish Creek Watershed with satisfactory results. The results of ET models will be directly applied to the operational hydrologic model (known as the Federal-State River Forecast Center Model) that currently is being used by the California Department of Water Resources. Comparison of simulated runoff values after and before using ET results as an input will provide the information necessary for evaluation of ET models. As a result of our coordination with the U.C. Davis NASA-Grant participants, (Algazi, et al) the Middle Fork of the Feather River Watershed was chosen as a test area on which to apply hydrologic data for the spring of 1975. Currently RSRP personnel are applying to this new watershed the ET estimation models which they previously had developed for the Spanish Creek Watershed.

Solar radiation is the major sources of energy for hydrological processes. Specifically, the quanitity of net radiation constitutes the key parameter in earth surface energy-balance equations utilized in hydrological modeling. A remote sensing-aided system developed by RSRP for solar radiation estimation is designed to give time and location-specific estimates on a watershed or subwatershed basis. This system utilizes some constant physiographic data and some climatic variables. Our methodology, as applied to Spanish Creek Watershed, has provided very satisfactory results. Solar radiation results, therefore, are being used as one of the major inputs in our evapotranspiration models.

In summary, our investigations have shown that remote sensing can cost-effectively provide much major input data required for hydrologic models. In several specific instances we have shown that the use of our methods can help water resources managers by making available to them better water resources inventories and more accurate water yield predictions, thereby permitting them to devise and implement better management practices. Based on such experience, as we near the end of our research on remote sensing as applied to water supply, we are preparing and refining various Procedural Manuals, as described in Appendix I, II and III.

3.400 CONTINUED RSRP RESEARCH ON WATER SUPPLY

The following continuing aspects of our work in the estimation of snow areal extent, snow water content, solar radiation, and evapotranspiration are summarized below:

1. Our concluding efforts to document both the nature and the performance of state-of-the-art water yield forecast models will soon be completed. This effort, carried out in coordination with the U.C. Davis NASA-Grant participants has been found to be necessary to fully evaluate both snow quantification and water loss eatimation procedures utilizing remote sensing techniques. Both the Federal-State River Forecast Center model (RFC model) and the snow quantification models used by California Cooperative Snow Survey (CCSS) continue to be examined. Performance documentation continues for the CCSS models and performance for the RFC model will be stated concisely in our next report within the context of the forecast assumptions and model inputs.

2. Development and application of water yield forecast models will be continued. This work includes refinement of sample design and technique development for estimation of snow water content, solar radiation, and evapotranspiration.

3. Concluding investigations will be made relative to the application of evapotranspiration and solar radiation models to our new watershed covering (as it does in order to better integrate our final tests with those of the Algazi group at Davis) the Middle Fork of the Feather River (MFFR). The models will continue to be examined, based on data acquired during the spring of 1975. Our concluding work on this MFFS watershed (MFFR) can be outlined as below, and in recognition of the fact that several of the listed activities already have been completed or nearly so:

   a. Watershed boundary determination
   b. Vegetation/terrain analysis
   c. Topographic analysis (elevation, slope, and aspect maps)
   d. Completion of existing climatic data collection
   e. Application of solar radiation models
   f. Completion of ground data collection
   g. Application of Level I evapotranspiration
   h. Modification and application of Level II evapotranspiration models and development of Level III ET models
   i. Performance of sensitivity analysis for different inputs in ET and color radiation models.

4. Sensitivity analyses will be completed for critical parameters in water supply models. In conjunction with the Algazi group, RSRP is developing water parameter (water loss) estimates to be included in current RFC and CCSS hydrologic models. The performance change in the models with and without these remote sensing-aided estimates, and based on the U.C. Davis system will be determined. Feedback on model performance will allow modification of the remote sensing-aided water parameter estimation sampling design and methodology so as to improve hydrologic model performance.

5. We soon will complete our evaluation of the costs of information-gathering using conventional and remote sensing-aided methods. This effort continues especially in the context of the RFC Sacramento River model and the CCSS volumetric model. Cost data on semi-automatic/automatic remote sensing-aided estimation of basin snow areal extent, snow water content, evapotranspiration, and solar radiation needs to be evaluated to a greater extent than has been possible up to the present time.

6. As a corollary to item 5, above, we soon will complete our analyses of cost-effectiveness of conventional vs. remote sensing-aided water supply estimation systems. In the near run, systems for estimating intermediate parameters used in ultimate water yield prediction will be compared. In the longer run, systems actually producing water runoff estimates also will be subjected to comparative analyses. Coordination here will be especially strong between RSRP and the Social Science group personnel of the Berkeley campus who continue to participate in this integrated study (see. for example Chapter 6 of the present report).

7. Development of an automatic (computerized) system for watershed-wide integration and interpolation of point data will be furthered. This system, when fully developed, would estimate the distribution of point data (i.e. precipitation) over the watershed of interest.

8. In light of progress made on the foregoing we will prepare:

   a. A final documentation of assumptions, structure, information levels, advantages, and limitations of remote sensing-aided systems for snow quantification and evapotranspiration estimation and

   b. A final version (insofar as our efforts under the present grant will permit) of procedural manuals on remote sensing as an aid for watershed-wide estimation of 4 factors of vital importance in estimating water supply in snow-covered areas, viz. snow areal extent, snow water content, solar radiation, and water loss to the atmosphere.

9. In addition to the above, as per agreement with our NASA monitors, we will prepare Procedural Manuals dealing with the use of remote sensing in the inventory and management of a given area's entire resource complex, (i.e. its timber, forage, soils, minerals, fish, wildlife and recreational resources in addition to its water resources). While a great deal of research leading to the preparation of such manuals could be performed to advantage, we believe that we can prepare a useful document by making maximum use of remote sensing-related work that we have done during the past several years for NASA Department of Interior and Department of Agriculture dealing with most of the above components of the total resource components.

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APPENDIX I

PROCEDURAL MANUAL

REMOTE SENSING AS AN AID IN DETERMINING THE AREAL EXTENT OF SNOW

A. Introduction

The term "areal extent of snow" pertains to the surface area of the terrain in a specified watershed that is covered with snow at a given time or seasonal state.

For many years the need for an improved method of estimating snow areal extent has been recognized by hydrologists and others concerned with the prediction of water runoff and the estimation of water yield, watershed-by-watershed. Among the methods showing greatest promise is the one dealt with in this Procedural Manual. That method seeks to make maximum use of modern remote sensing techniques, including those which result in the acquisition of aerial and/or space photography of the watershed at suitably frequent intervals. Because of an advantage known as the "synoptic view", it is possible on space photography, and even on high-altitude aerial photography to cover vast watershed areas with only a very few frames of photography. As will presently be seen, this advantage can be of great importance to those wishing to use such photographs as an aid in determining the areal extent of snow.

Of the several remote sensing-based techniques that have been developed for estimating snow areal extent only two will be mentioned here since they appear to be both representative and highly promising. The first is based merely on the delineation of the apparent snowline on the photographs. The delineated portions of the photographs are then measured in such a way as to provide an estimate of the areal extent of the snow-covered area. This technique is described fully by Barnes and Bowley (1974).

A second technique has been developed which utilizes a two-stage sampling scheme to arrive at an estimate of the snow-covered area. The procedure for employing this technique is described herein. As will presently be seen, the technique employs as much ancillary (i.e., non-remote sensing-derived) information as possible to aid in the accuracy of the final estimate. Furthermore, the design of the model that is employed when this technique is used is such as to largely eliminate final estimate discrepancies, even when two or more photo interpreters are used as a team, since a statistical evaluation of each photo interpreter's results is made. The method, overall, is sufficiently simple and inexpensive to permit it to be used in addition to, rather

than instead of, more conventional methods, thereby providing additional confidence in the final estimate of snow areal extent on which operational decisions must be made, in any given instance, by the hydrologist or other resource manager.

When this second method is used by a competent image analyst, in addition to his determining the total area that is covered with snow, he also derives detailed locational information of great value, i.e., he determines the exact portions of the watershed that are snow-covered and differentiates them from the snow-free areas. This can be of great advantage in relation to his desire to make accurate estimations of water yield and water runoff rates because the rate of snow depletion for a given portion of the watershed obviously is a function of its slope, aspect, vegetative cover, and other locally-variable factors.

B. Procedure

The procedure described here for estimating areal extent of snow is based upon a two-stage analysis of remote sensing imagery. The first stage entails the use of Landsat* color composite imagery while the second stage employs low-altitude, large scale aerial photography. The following description provides a step-by-step guide to the use of this method in estimating the areal extent of snow:

Step 1. Prior to the start of the winter season (i.e. the season when the snowpack is to be measured) all of the projected dates when Landsat will be overflying the area of interest during the snow survey period should be systematically listed. In compiling this list one should keep in mind that there is sidelap of about 20 to 30 percent (depending upon the latitude of the area) between the 115-mile swath that is covered by Landsat on one day and that which the same vehicle covers on the following day. Therefore, this factor needs to be considered as the list is being made of all possible dates for the acquisition of Landsat imagery of the area of interest.

Step 2. During the snow-survey period, on each date when a Landsat overflight of the area of interest is about to be made under what is predicted to be suitably cloud-free conditions, by prior arrangement steps should be taken to procure nearly simultaneous low-altitude aerial color photography of preselected flight lines, thereby acquiring the previously mentioned "second stage sample". An optimum scale for such photography is approximately 1/30,000, and 35mm negative color film is preferred.

*The term "Landsat" applies to various unmanned earth resources technology satellites (formerly called "ERTS"), each of which provides images of the surface of the Earth on an 18-day sun-synchronous cycle (0930 local sun time, approximately) from an altitude of approximately 570 miles and covering a swath width of approximately 115 miles.

Step 3. The second stage photography procured in Step 2, above, should be promptly processed and from it standard "3R" prints (i.e., size 3-1/2" x 5") should be made.

Step 4. As promptly as possible after the corresponding Landsat overflight has been made, and again by prior arrangement (in this case normally with the EROS Data Center at Sioux Falls, South Dakota) black-and-white MSS (multispectral scanner) transparencies should be obtained from bands 4, 5 and 7 covering the entire watershed area of interest. The standard 9" x 9" transparencies produced by the EROS Data Center are preferred. In addition, either at the time when the first of this snow-season Landsat photography is being acquired, or at some earlier date, an additional summertime (snow-free) set of Landsat imagery also should be acquired for comparative analysis, as indicated below (see Step 15).

Step 5. In each instance, on the Landsat imagery that has been acquired the boundary of the watershed or other area of interest should be delineated.

Step 6. For each of the frames of Landsat imagery required in making the delineation of Step 5, a simulated color infrared color composite should be made, using the three bands (4,5 and 7) to make a "triple exposure" on negative color film in the manner described in Appendix 1 of this Procedural Manual.

Step 7. From the resulting negative color composites, reflection prints (rather than transparencies) should be made to a size of approximately 8" x 10". In those instances where more than one Landsat frame is required to cover the area of interest, the Landsat frames originally selected (and the corresponding areas copied and printed from them) should overlap each other sufficiently to provide complete coverage of the entire watershed or other area of interest.

Step 8. Either at the time when the first of the wintertime Landsat sets of imagery is obtained, or prior thereto, a set of acetate overlays, each about 9" x 9" in size and gridded at various intervals into squares, should be prepared. In any given instance the size of the grid should be governed by time, accuracy, and cost constraints. Obviously, in most instances as grid size decreases, the accuracy, cost and time factors all increase.

Step 9. Through the use of geographic features that are readily located on Landsat imagery, each successive frame of such imagery should be indexed so that the gridded acetate overlay can be registered in exactly the same way with respect to each of the frames that cover a given area.

Step 10. Similarly, the grids, as they appear on the Landsat frames of imagery, should be transferred to the low-altitude photos (i.e., the stage two photos taken at large scale with 35mm color film) and then labelled in such a manner that any grid unit (i.e., any image sample unit) can be easily located there and readily cross-referenced to the corresponding Landsat imagery.

Step 11. The indexed grids as they now appear on the low-altitude photography should be interpreted for areal extent of snow. Generally four to six snow-cover classes should be used, based on the proportion of the grid that appears to be snow-covered. An example using six classes could be: Class 1, 0-19 percent; Class 2, 10-25 percent; Class 3, 25-50 percent; Class 4, 50-75 percent; Class 5, 75-90 percent; Class 6, 90-100 percent. (It has been found that, due to the large amount of detail visible on the large scale prints it is a fairly easy task for each grid unit to be placed in a specific class with a high degree of certainty.)

Step 12. This set of classified grid units should now be divided into a training and a testing set. The training set should be located on the gridded acetate overlays to the Landsat imagery and should include a wide range of snow appearance types covering the range of snow-cover classes.

Step 13. The interpretation set-up should now be constructed. It should consist of a coincident image viewing device, such as a mirror-stereoscope or a transfer scope, the set of 8" x 10" Landsat summer color composite prints, for which the determination of snow areal extent is to be made, and the set of classified grid units, as seen on the low-altitude aerial photography, corresponding to the gridded winter color composite prints.

Step 14. As the detailed interpretation of the Landsat winter photos begins, one 8" x 10" summer Landsat print should be placed under the stereoscope (or transfer scope) along with the corresponding scene on the gridded winter Landsat print set. The prints should be adjusted so that conjugate images can be fused by the photo interpreter (i.e., so that all common features can be made to coincide with each other, one image viewed with each eye), thus allowing the interpreter to assess both the snow areal extent and the vegetation/terrain conditions in each grid unit.

Step 15. The interpreter should next engage in the task of training himself to recognize different snow-cover condition classes within grid units based on: (a) underlying vegetation/terrain features (as seen on the summer Landsat print), (b) the snow cover visible on the gridded winter Landsat print, and (c) the appearance and subsequent classification of the grid units as seen on the low-altitude aerial photography.

By viewing through the coincident image device and observing how each grid unit in the training set appears during the winter and summer, and by then referring to the training set grid units on the low-altitude aerial photography, the interpreter can effectively complete this training task in very short order.

Step 16. Once trained, the interpreter should then proceed to classify each grid square on the winter Landsat print (in terms of the snow areal extent class to which it belongs) according to his synthesis of the information available as he perceives it on the summer and winter Landsat prints.

Step 17. After all of the winter dates of imagery have been classified, the interpreter's initial interpretation results are ready for the testing phase. Therefore, at this point the results of the grid classification (as made on the low-altitude aerial photography testing set) should be compared to the results obtained by the interpreter in all applicable grid units. A ratio estimator statistic, as described in detail in Appendix 1 of this Procedural Manual should then be applied. This statistic will provide the adjustment calibration necessary to correct the interpreter's initial interpretation results.

Note: It is apparent from the foregoing that, even if this procedure is highly successful, its end product is merely an accurate determination of the areal extent of snow, together with an accurate delineation of each portion of the watershed area according to the snow-cover class to which it belongs. This is an essential step leading to a prediction of water runoff and the estimation of water yield. The remaining steps are discussed in other procedural manuals.

A Specific Case Study

The following case study describes uses that our RSRP personnel have made of the foregoing procedure for the Feather River Watershed, California.

On April 4, 1973 the majority of the Feather River Watershed (located in the central Sierra Nevada Mountains, California) was imaged in a virtually cloud-free condition by the Landsat Satellite In order to document the existing ground conditions in greater detail than that provided by the satellite imagery, a photographic mission was flown over the watershed on April 6, 1973. Four transects were flown using a motorized 35mm camera to acquire photography at a scale of approximately 1:30,000 on the negative.

Landsat imagery from August 31, 1972 was chosen for use as the vegetation/terrain base for the snowpack analysis procedures. The August 31 and the April 4 Landsat images of MSS bands 4, 5 and 7 were photographically combined to produce simulated color infrared enhancements on color negative film using the previously mentioned technique.

The simulated color infrared enhancement of the August 31, 1972 Landsat scene was photographically reproduced to give a 16" x 20" color print of approximately 1:250,000 scale. The April 4, 1973 Landsat color infrared enhancements were enlarged to precisely the same scale as the August 31, 1972 imagery and printed to give overlapping 8" x 10" prints.

An acetate grid (each grid block equalling approximately 2000 meters on a side at a scale of approximately 1:250,000) was attached to the vegetation/terrain Landsat image. The grid blocks, termed image sample units (ISU), were transferred to the large scale photography where applicable. The image sample units on the large scale aerial photography were coded as shown in Table 1 .

Table 1

Definition of the five classes used in this snow areal extent estimation problem

Code	Snow Cover Class	Midpoints
1	No snow present within ISU	0
2	0-20% of ISU covered by snow	.10
3	20-50% of ISU covered by snow	.35
4	50-98% of ISU covered by snow	.74
5	98-100% of ISU covered by snow	.99

The interpreter then engaged in the training phase to familiarize himself with the imagery and image classification technique. Once trained, the interpreter proceeded to classify all the image sample units on the 8" x 10" Landsat color print for the winter dates. A more detailed description of this process will be found in steps 12-16 of the preceeding Section B – Procedure.

The classified imagery was then subjected to statistical analysis. The following are the results from the April 4th Landsat areal extent of snow analysis.

Snow Cover (Condition) Class

	1	2	3	4	5
Total number of ISU's Classified per class	403	289	214	453	859

To derive the approximate number of hectares in each class, the image sample unit totals per class were multiplied by the number of hectares per image sample unit (400) with the results indicated below:

Snow Cover (Condition) Class

	1	2	3	4	5
Hectares	1.612×10^5	1.156×10^5	8.56×10^4	1.812×10^5	3.436×10^5

Then to establish the approximate amount of actual snow-covered area per class, the number of hectares/class were multiplied by the snow cover class midpoints (from table 1) for each class, as indicated below in the following tabular summary:

Snow Cover (Condition) Class

	1	2	3	4	5
Snow Cover Condition Class Midpoint	0	.10	.35	.74	.99
Hectares of snow per class	0	1.156×10^4	2.996×10^4	1.341×10^5	3.402×10^5

Table 2

Interpretation results of the testing phase, areal extent of snow estimation for the April 4, 1973 Landsat and April 6, 1973 large scale aerial photographic data.

Landsat Image Data: Space Cover Condition Class	Large Scale Aerial Photographic Data: Snow Cover Condition Class 1	2	3	4	5
1	6	1			
2		10		1	
3		2	6	2	
4			1	12	
5				6	33

Key to Table 2: $\boxed{f_i}$

where f_i = Image sample unit interpretation frequencies

i = Index for Table 2

Table 3

Interpretation results of the testing phase, areal extent of snow estimation for April 4, 1973 Landsat and April 6, 1973 large scale aerial photographic data. Also included is a listing of uncorrected large scale aerial photographic and Landsat image estimates of snow areal extent per image sample unit by snow cover class.

		Large Scale Aerial Photographic Data: Snow Cover Condition Class				
Landsat Image Data	Snow Cover Condition Class	1	2	3	4	5
		0 0 6	40 0 1			
	2		40 40 10		296 40 1	
	3		40 140 2	140 140 6	296 140 2	
	4			140 296 1	296 296 12	
	5				296 396 6	396 396 6

Key to Table 3: $\begin{array}{c|c} & Y'_i \\ X_i & f_i \end{array}$

where: X'_i = Landsat image estimate of snow areal extent per image sample unit by snow cover condition class in hectares

By adding the hectares of snow per class together, the total surface area of snow in hectares was established. Thus for the April 4, 1973 Landsat date the estimate of snow areal extent was found to be 5.158×10^5 hectares. This value, however, may be biased by any errors which occured during the classification of the Landsat image sample units for snow areal extent. The uncorrected areal extent of snow estimate can be "corrected" by comparing the interpreter classification results with a series of preselected, preclassified image sample units, chosen for testing purposes from the large scale aerial photographs.

Interpretation results not falling in a given snow cover condition class for both the large scale aerial photographic and Landsat image data represents a misclassification of image sample units by the interpreter from Table 2. Thus it can be seen that 13 out of a possible 80 image sample units misclassified. This misclassification error can then be represented by a statistic, the population ratio estimator (Cochran, 1959) which will be used to correct the initial areal extent of snow estimate of 5.158×10^5 hectares derived from the Landsat image classification.

The statistical approach is defined as follows:

$\hat{Y}_r = X\hat{R}$ = the final, corrected areal extent of snow estimate

where: $X = \sum_{j=1}^{N} X_j$ = the uncorrected Landsat areal extent of snow estimate

given that: X_j = the Landsat interpretation estimate of snow areal extent per image sample unit by snow cover class

j = the index for all Landsat image sample units

N = the total number of Landsat image sample units classified for snow areal extent

where: $\hat{R} = \bar{Y} \div \bar{X}$ = the population ratio estimator

given that: $\bar{Y} = \left(\sum_{i=1}^{n} Y_i \right) \div n$ = average snow areal extent value for the large scale photographic image same unit estimates

$\bar{X} = \left(\sum_{i=1}^{n} X_i \right) \div n$ = average snow areal extent value for the Landsat image sample unit estimates.

and that: n = the total number of image sample units used in the testing phase

i = sampling index

y_i = large scale photography snow areal extent estimate for image sample unit i

X_i = Landsat snow areal extent estimate for image sample unit i

Since the uncorrected Landsat areal extent of snow estimate (X) has been calculated to be 5.158×10^5 hectares, the value for the population ratio estimator, R, must be determined to solve for the final, corrected Landsat areal extent of snow estimate, $\hat{Y}_r$, (from the equation $\hat{Y}_r = X\hat{R}$). Table 3 represents an expanded version of Table 2 designed to facilitate the calculation of the population ratio estimator, $\hat{R}$. The table ha been enlarged to include listings of snow cover condition class/image sample unit, specific large scale photography estimates of snow areal extent and Landsat areal extent of snow estimates.

y_i = large aerial photography estimate of snow areal extent per image sample unit by snow cover condition class in hectares

$$= \begin{bmatrix}\text{snow cover condition class} \\ \text{midpoint}\end{bmatrix} \begin{bmatrix}\text{number of hectares} \\ \text{per image sample unit}\end{bmatrix}$$

and;

f_i = image sample unit interpretation frequencies

additionally,

n = the number of image sample units used in the testing phase

$$= \sum_{i=1}^{K} f_i = 80$$

where: i = index for Table

and k = the number of interpretation result blocks in Table = 11

$\hat{R}$, the population ratio estimator, can now be calculated by solving for $\overline{Y}$ and $\overline{X}$ from the data presented in Table 3 . Thus, if

$$\bar{X} = \sum_{i=1}^{K} f_i X_i \div n$$

and $$\bar{Y} = \sum_{i=1}^{K} f_i y_i \div n,$$

then $$X = 264.15 \text{ and } Y = 259.80$$

Consequently, the population ratio estimator is calculated to be .9835 (recall that $\hat{R} = \bar{Y} \div \bar{X}$).

Finally, to solve for $\hat{Y}_r$, the final, corrected areal extent of snow estimate, the population ratio estimator is multiplied by the uncorrected Landsat snow areal extent estimation. Thus,

$$\hat{Y}_r = X\hat{R} = (5.158 \times 10^5)\ (.9835) = 5.073 \times 10^5 \text{ hectares.}$$

APPENDIX II

PROCEDURAL MANUAL

REMOTE SENSING AS AN AID IN DETERMINING THE WATER CONTENT OF SNOW

1.0 Introduction

This procedural manual describes the use of Landsat data in combination with conventional ground snow course data to provide an estimate of watershed or subbasin snow water content. The technique is designed to be readily implementable in current operational water runoff forecasting models. Only a small initial capital investment is required and man-time requirements need not be substantial. The technique is designed to complement current snow measurement methods by providing spatial information on snow water content. Consequently it permits more accurate estimates to be made on a basin or subbasin basis. Normally, snow water content estimates are obtained directly from ground-based snow course or snow sensor measurements. The procedure described herein introduces a stratified double sampling approach that relates the ground-based estimates to snow areal extent data gathered from Landsat imagery. The resulting relationships enable low-cost remotely sensed data to statistically characterize the spatial and temporal variability of specific snow depletion environments sampled with ground snow course data. In this manner, satellite data can be used to determine the weight assigned to a particular snow course measurement and also to provide more frequent assessment of snow water content.

For determining snow areal extent, itself, this technique utilizes the Landsat-based procedure described in our Snow Areal Extent Procedural Manual as the remote sensing input. However, non-Landsat remotely sensed data types could potentially provide useful information to characterize the spatial variability, watershed-wide with respect to snow water content. For example, meteorological satellite data could be used with the Snow Areal Extent Procedure to provide more frequent (daily) information, although of lower spatial resolution, basin-wide. The technique can also be refined by the user, if desired, to include machine processing of the satellite data.

2.0 General Approach

The following provides an overview of the remote sensing-aided snow water content estimation procedure.

Sample Design and Measurement

A stratified double sample method is used to develop a basin-wide estimate of snow water content. Under this approach, snow water content information for the whole watershed, as obtained inexpensively on a sample unit basis from Landsat data is combined with that gained from a much smaller and more expensive sample of ground-based measurements at snow courses (see Figure 13). The result is a basin-wide estimate of snow water content based on Landsat data calibrated by regression on snow course data. Since much of the watershed snow wter content variation is accounted for by information gained from the Landsat sample stage, an overall estimate of basin snow water content is possible at more precise levels than available for the same cost from conventional snow course data alone.

The sequential sampling/measurement process proceeds by first locating a sample grid over the watershed. Snow areal extent estimates are quickly made for each sample unit by manual techniques (See Snow Areal Extent Procedural Manual) for the previous snowpack build-up dates and then for the specific forecast date. The snow areal extent data is then combined by a linear equation to generate an index parameter that is correlated with snow water content information that is specific to the forecast date for each sample unit. This linear model is designed to reflect the relationship between snow areal extent and snow depletion behavior, and is specific to the watershed being studies. Some users may choose to develop more complex, physically realistic areal extent-to-water content transformations.

By specifying the precision and level of confidence desired in the basin-wide snow water content estimate and by considering measurement costs in relation to the available budget, one is able to calculate the necessary ground subsample size. Ground snow water content measurements are then allocated to Landsat-based snow water content-index classes (strata) according to weighted random stratified sampling procedures.

Regression relationships are developed between the Landsat snow water content index data and the ground snow water content measurements. These equations are then used to correct all Landsat-based data by ground values of snow water content. The ground corrected values of Landsat-based snow water content information in each stratum or class are added to give a total basin-wide estimate of snow water content, together with an associated precision statement.

STRATIFIED MULTIDATE LANDSAT DATA PLANE
CALIBRATED BY SNOW COURSE MEASUREMENTS
FOR WATERSHED SNOW WATER CONTENT ESTIMATION

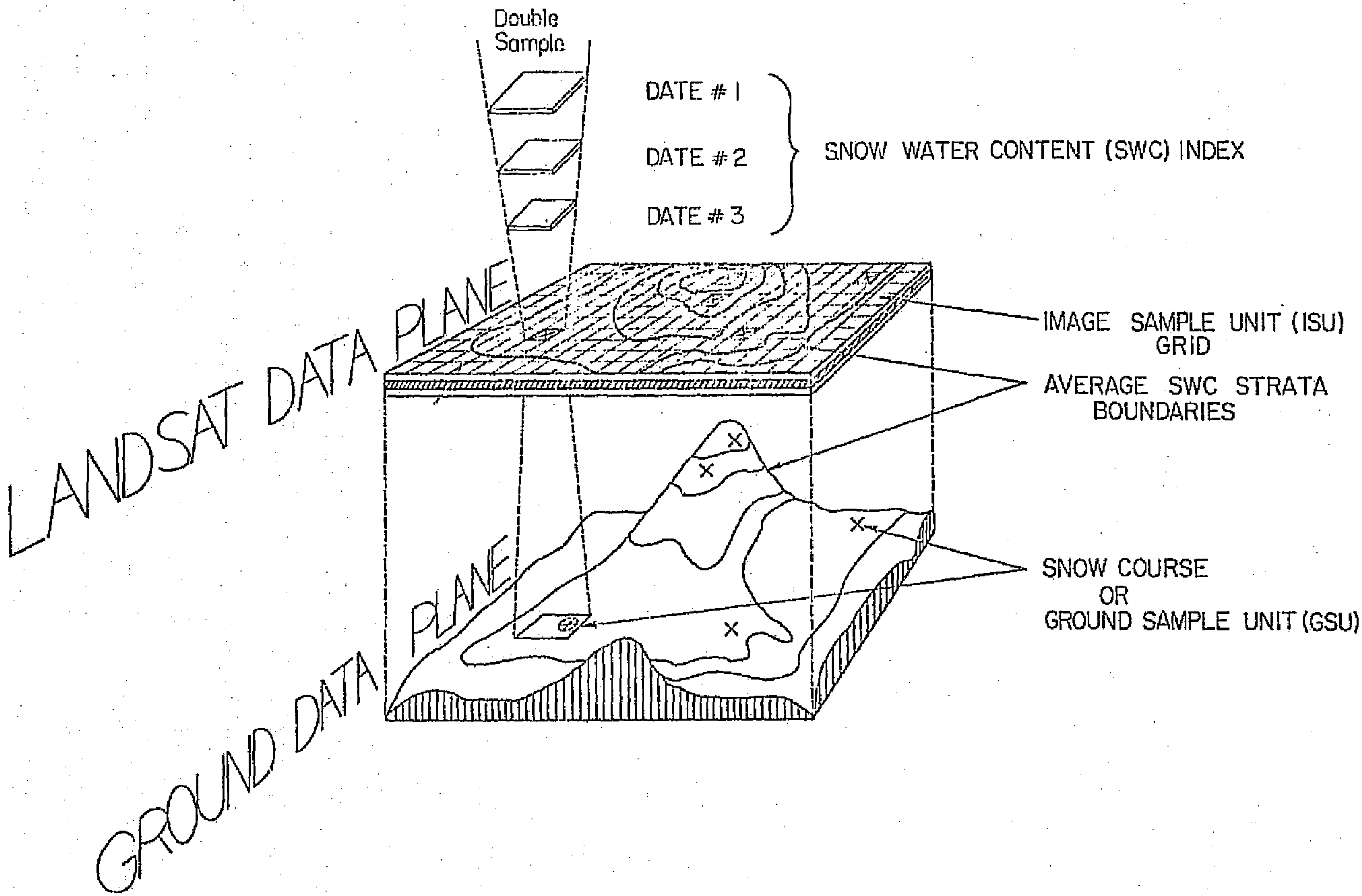

Figure 13. Stratified Multidate Landsat data plane calibrated by snow course measurements for watershed snow water content estimation.

Results and Their Applications

The Landsat-aided snow water content estimation procedure is designed to generate an estimate of total watershed snow water content and an associated statement of precision for a given forecast period. The estimate may then be related by regression equations directly to basin water yield for a given period. Or the statement may be used as another predictor variable in current snow survey or river forecast equations. Grid overlays, when placed either on watershed maps or directly on Landsat imagery, give a location-specific estimated snow water content index for each sample unit. Such information can be used to produce improved hydrologic modelling procedures incorporating this spatial data.

Performance Criteria

Performance criteria for this procedure consist of 1) the precision and accuracy of the estimate of snow water content over the watershed versus the cost of making the estimate, 2) the timeliness of the estimate; and (3) the value of any in-place map products of improved quality that can be produced through use of the procedure.

3.0 MATERIALS AND METHODS

The stepwise procedure for estimating snow water content with the aid of remote sensing is described below:

Step 1: An overall plan should first be developed which will facilitate adoption of the remote sensing-aided snow water content estimation procedure by the user organization. This implementation plan should consider (1) available budget, (2) requirements for either training or obtaining image interpreter(s), (3) type of products desired, e.g. watershed and/or sub-water shed estimates or in-place snow water content maps (4) performance requirements in terms of estimate precision and satellite image acquisition to forecast turnaround time requirements (5) interface of the snow water content procedure with current operational forecasting operations, and (6) startup equipment (stereoscope, photographic laboratory facility) and labor requirements.

Step 2: Color composites should be prepared from Landsat imagery and/or from other satellite imagery types, (e.g. weather service) and the appropriate image sample unit (ISU) grid should be placed over each watershed of interest. In the performance of this step, black-and-white Landsat transparencies should be obtained (e.g. from the EROS Data Center) and transformed into a simulated infrared color composite by a sample photographic procedure described in our "Snow Areal Extent Procedural Manual". In the color-combining process, an ISU grid is

randomly placed over each image so as to cover the watershed of interest. Watershed boundaries should be located on the satellite imagery from 1:250,000 scale U.S. Geological Survey topographic data via use of optical rectification devices (if available) or by maqual transfer from map to image. A complete description of the boundary and sample grid overlay is given in the Snow Areal Extent Procedural Manual. Grids on all dates must be in common register. Square image sample units each 400 hectares in size, are recommended. This size is large enough to stabilize variance and small enough to give location-specific snow water content-related information at reasonable cost. The user may choose to modify these image sample unit dimensions as experience is gained with the estimation procedure.

Step 3: The snow areal extent should then be estimated for each Landsat ISU for previous season(s) or current season snow build-up dates. Each ISU should be interpreted, manually, as to its average snow areal extent cover class according to a snow environment-specific technique described in the Snow Areal Extent Procedural Manual. Previous dates of imagery used should include: 1) one of the images covering the average date of maximum snow accumulation in an average snow year; 2) at least one image from an early season snow date in the current snow season; and 3) if possible, another image from a date well into the snow season representing average snow distribution for that date. As will later be discussed in Step 5, these previous snow season images are used to maximize the correlation between the satellite-derived snow water content indices and ground measurements of snow water content for any given sample unit on the forecast date in question.

Step 4. Snow areal extent should be estimated by ISU for Landsat snow season forecasting date of interest, again using the procedure described in the Snow Areal Extent Procedural Manual. Length of the delay that can be tolerated between image acquisition by the satellite and imagery receipt by the user will depend on the use of the snow water content estimate. A very short turn-around times (hours) will be required for weekly or sub-weekly water yield forecasts, but longer times usually will be satisfactory for monthly or seasonal forecasts.

Step 5: Snow areal extent data should next be transformed to snow water content data by Landsat ISU. Snow water content is estimated from the following first order, time-specific model, designed to reflect physical snow depletion behavior in a given melting environment:

$$X_i = \sum_{j=1}^{J} (M_{ij}) \; (G_j) \; K_i$$

where X_i = estimated snow water content index for image sample unit i, correlated to corresponding actual ground snow water content data,

M_{ij} = snow cover midclass point based on photo interpretation; expressed on a scale of 0.00 to 1.00 for image sample unit i on the jth Landsat snow season date,

G_i = weight (related to snow depletion zone behavior characteristics) assigned (0.00-1.00) to a past M_{ij} according to the date of the current estimate,

K_i = the number of times out of j that sample unit i has greater than zero percent snow cover, and

J = total number of snow season dates considered.

The basic assumption of this simple model is that the greater the sum of areal snow extent over all dates used and the more often snow is present, the higher will be the expected snow water content. This model is most appropriate in mountainous environments. Each user may want to specify a more sophisticated, and more physically realistic model for his own watershed(s).

Definition of the weighting factor, G_j, will be watershed specific. Generally, weights should approach 1.00 as the dates of imagery approach the date of forecast. The justification of the weighting relationship is that successively more recent climatic events have progressively more importance in determining the actual snow water content on the forecast date in question. To insure reasonably high correlation between X_i and corresponding snow water content values, there usually should be at least three snow season dates considered ($j \geq 3$). Normally, one or two dates of Landsat imagery would be required during the early snow accumulation season. Occasionally, j may be only two, such as when the first date consists of an April 1st snow water map, based on the past year's Landsat data, and the second is the current early snow season date in question. In all cases the sample unit grids on all dates must be in common register with respect to a base date grid location. Starting initial weight suggestions are : 0.25 for the previous year image that is representative of an average maximum snow accumulation date; 0.50 for the early snow season date; 0.75 for dates occurring a month or two before the forecast date; and 1.00 for the forecast date and for all dates occurring within one or two months prior to the forecast date.

Step 6: The ISU's should next be classified and summarized into snow water content strata. Stratification is used to minimize the variance of the final snow water content estimate. Wtihout prior experience on a given watershed, it is best to define two or three strata for first implementation. These strata can be defined by dividing the range of ISU snow water content index values over the watershed into two or three natural groupings (seen by plotting snow

water content index versus number of ISU's). If no natural groupings are present, then the range of ISU snow water content index values should be divided into two or three ranges having approximately equal numbers of ISU's in each stratum.

After each ISU has been coded as to its stratum, the number of ground sample units (GSU's) consisting of snow courses required to satisfy the precision user criterion (allowable error), as established by the user for the snow water content estimate, should be calculated by stratum. (The procedure which our group would consider most suitable for sample size determination on the ground is in the process of development).

Initial implementation of this procedure requires previous information regarding the variability, in each stratum, of the snow water content index, and also a determination of the correlation between ISU and GSU data, the total number of ISU's needed per stratum, and average ISU and GSU costs. This data is most efficiently gained by obtaining Landsat data for a previous snow season that was as similar to average as possible. Steps 1 through 5 should be followed for a mid-season snow date. The stratification portion of Step 6 should then be performed to classify ISU's into strata from which the total number of ISU's per stratum is immediately gained. The variance in Landsat snow water content index by stratum can then be calculated by the standard statistical formula for variance. Next, current ground snow courses and snow sensor locations should be determined relative to the given ISU in which they fall. The overall correlation coefficient between ground snow water content measurements and Landsat-based snow water content index values should then be calculated for the matched ISU's and GSU's. Additional correlation coefficients also should be determined for each stratum if a sifficient number (e.g. ≥ 10) of snow courses exist for each stratum.

Image preparation and interpretation costs should also be documented during this initial exercise. Labor, materials, and overhead costs should be documented on an ISU basis as in the example given in Table . Cost per GSU (snow course) measurement can be st be developed from the individual user organization's pre-existing data. All cost data for sample allocation should represent operational costs.

<u>Step 7:</u> For the first year of actual implementation, the calculated number of GSU's per snow water content index stratum should be allocated for given ISU's in those strata. This allocation should be based on equal probability selection from the tabular summaries of ISU's generated in Step 6. Consequently, ISU's should be numbered from 1 to N_h in a given stratum and a random number table (or calculator/computer analogue) used to select the calculated number of ISU's to which GSU;s will be matched.

TABLE 1. EXAMPLE CALCULATION OF IMAGE SAMPLE UNIT COSTS FOR A LANDSAT-AIDED MANUAL SNOW WATER CONTENT INVENTORY[1]

	Total Cost	Cost per ISU[2]
I. Pre-Inventory		
A. Image Acquisition		
3 LANDSAT dates with 3 bands per date @ $3 per band; the costs of 2 of these dates amortized over 5 dates	$12.60	$.006
Resource Photography		
(Medium Scale Aerial Photography for Image Analyst Environmental Type Training)	$14.29	$.006[3]
B. Image Sample Unit		
Grided LANDSAT Color Composite Print Generation		
Film, Processing, and Printing		
3 dates @ $11 per date		
The costs of 2 of these dates amortized over 5 dates	$15.40	$.007
Labor 0.5 hours per date @$13.50/hr including overhead, 3 dates, the costs of 2 of which are amortized over 5 dates	$ 9.45	$.004

1. Cost data based on 1975 University of California figures.

2. Cost per image sample unit assuming 2218 (780,000 ha test watershed) image sample units in the watershed(s) of interest.

3. Two $500 flights amortized over 5 years, 7 dates per year, and two watersheds.

TABLE 1 (continued)

	Total Cost	Cost per ISU
II. Inventory		
A. Interpreter Training		
1 hr per date, @ $13.50/hr 3 dates, the costs of 2 of which are amortized over 5 dates	$18.90	$.009
B. Image Interpretation		
Ave. 6 hrs per date @ $13.50/hr (2218 Image Sample Units)		
3 dates, the costs of 2 of which are amortized over 5 dates	$113.40	$.051
C. Data Keypunching		
6 hrs per date @ $13.50/hr; 3 dates, the costs of 2 of which are amortized over 5 dates	$113.40	$.051
D. Computer Analysis of Image Analyst Results		
0.075/hr @ $40/hr	$ 3.00	$.001
E. Selection of Random Numbers to Define Ground Sample Units		
0.5/hr @ $13,50/hr amortized over 5 dates @ $13.50/hr	$ 1.35	$.001
TOTAL	$301.79	$.136

The snow course or sensor should be located in a snow accumulation and depletion environment representative of the average of such environments covered by the given ISU. If it is not efficient to reallocate an already established network of snow courses and sensors, then the snow water content stratum should be identified for each such ground unit by determining the stratum associated with the ISU covering that ground location. After several years of using this remote sensing-aided technique for snow water content estimation, the user may find it desirable from a precision (i.e. variance control) standpoint to reallocate some ground courses to achieve the optimum stratum-by-stratum GSU sample sizes calculated previously. However, before this is done, updated GSU sample sizes should be calculated using stratum-specific ground or image snow water content variance data averaged over successive seasons.

Step 8: Estimates of watershed or sub-watershed snow water content should be calculated, using the equation described in step 5. The values thus obtained should be entered into statistical or physical models to predict water yield. For example, the user could employ the remote sensing-aided snow water content estimate as an input variable in a regression equation for predicting water runoff.

Step 9: Finally, the utility of the above-described procedure for using remote sensing as an aid to estimating snow water content should be evaluated in meeting the water yield forecasting organization's legal or contractual requirements. Utility can be judged by new information gained (e.g. watershed physical relationships), forecasting accuracy or precision improvement, cost savings, or forecast timeliness. Information gained on the precision/cost effectiveness of the procedure and the sensitivity of the water yield forecast models to the resulting snow water content estimates can be used to:

1) refine the model (Step 5) used to calculate the snow water content index,

2) better define snow water content index strata,

3) generate better GSU sample sizes and allocation strategies, and

4) refine the actual snow areal extent interpretation and imagery enhancement and analysis procedures used in Steps 2, 3 and 4.

CHAPTER 4

REMOTE SENSING OF AGRICULTURAL WATER DEMAND INFORMATION

Co-Investigator: John E. Estes, U.C. Santa Barbara

Contributors: John Jensen, Larry Tinney, Sue Atwater, Tara Hardoin

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4.0 ABSTRACT

Agricultural water demand information for arid or semi-arid climates is important for effective water resource management. Remote sensing methodologies utilizing high altitude photography or LANDSAT imagery provide accurate, economic alternatives to conventional survey techniques. Manual and digital remote sensing techniques described herein are capable of producing information for semi-operational water demand predictions by California state and county agencies who must maximize the use of the finite amount of local, state and federal water.

4.1 INTRODUCTION

Food and energy production are primary research frontiers for the future. A recent study by a major research organization predicts the following effects of world exponential population growth to impact mankind during the 1980 to 2000 period:[1]

* intensified landuse pressures and a growing list of critically short mineral resources will come into being
* international trade of all types will reach a new high with particular increases in foodstuffs, minerals, and energy;
* international cooperation in agricultural research and production will increase as the world seeks to maximize its ability to feed itself;.

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[1] The TERSSE study (Total Earth Resources Systems for the Shuttle Era) was conducted by General Electric for the National Aeronautics and Space Administration to identify high priority areas for the 1980-2000 time frame. Many of the findings in this study are based on an assumed population growth from 3.2 billion in 1973 to around 7 billion in the year 2000. General Electric Space Division: <u>Definition of the Total Earth Resources System for the Shuttle Era</u> (General Electric, Philadelphia, 1974) Vol. 3, p. 4.

* government funded research and development coupled with the use of large scale modeling data banks will increase in societies such as the United States where government is expected to act as the catalyst to conduct resource ecological surveys.

In the United States, there is enough water to meet projected agricultural demands to the year 2000 given the amount of countrywide precipitation and groundwater supplies. A major problem, however, is that often this water is not where the demand exists[2] (see Figure 4-1). One response has been the development of large scale water transport projects. The State Water Project and All-America Canal in California, and the Welton-Mohawk Project in Arizona are recent prime examples of our technological response to such conditions.[3] Another response is to drill more and deeper wells, essentially mining groundwater supplies.[4] One has only to examine temporal LANDSAT images of the Colorado High Plains, Texas, Kansas, Nebraska, and the Dakotas to see the proliferation of center pivot irrigation systems mining groundwater in these areas.[5]

The effective management of inter-regional water transport and increased groundwater extraction is dependent upon accurate water supply and demand statistics at the regional, state, national, and even international level. The basic need for such information caused investigators conducting the TERRSE[6] study for the National Aeronautics and Space Administration (NASA)

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[2] U.S. Department of Agriculture: Recommendations on Prime Lands. (U.S. Government Printing Office, Washington, D.C. 1976), pp. 22-23.

[3] Estes, John E. and Leslie W. Senger: Remote Sensing for Monitoring a Water Transportation Project - The California Aqueduct. Paper presented at the XII Congress of the International Association of Aeronautics and Astronautics (Baku Azerdaydzhai, USSR, 1973).

[4] Falkenmark, M. and G. Lindh: "How Can We Cope with the Water Resources Situation by the Year 2015?" Ambio Vol. 3, pp. 114-122.

[5] Bowden, L. W. (ed.), 1975. Manual of Remote Sensing, Vol. II, Falls Church, Va. American Society of Photogrammetry, pp. 1973-1978. Also see Poracsky, J., 1976, "Distribution of Center Pivot Irrigation Systems in Southwest Kansas," University of Kansas Center for Research, Inc., Tech. Rept. SAL-7606.

[6] The basic criterion for the inclusion of a mission was that there be a reasonable change of the mission being performed during the 1980's time frame under consideration. Definition of the 30 missions were based on the following inputs to the study: 1) mandated tasks of Major Federal Organizations; 2) information requirements of the Other Dominant Organizations; and 3) assessment of the relative amenability of the information classes to remote sensing. On the basis of a review and evaluation of these inputs a list of 40 basic TERSSE missions was synthesized. General Electric Space Division, op. cit. (see Footnote 1 above), pp. 3-11.

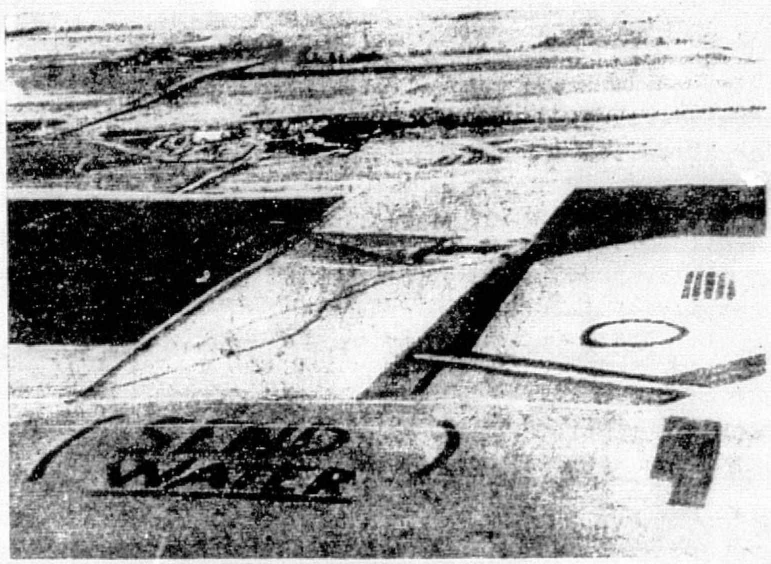

FIGURE 4-1. While the Pacific Northwest received its usual abundant rainfall in 1976, the midwest United States suffered a severe water shortage. South Dakota farmer Don Clelland, suffering through the long drought, took his case to a higher court. He plowed a plea for rain into a stubble field. (Associated Press Wirephoto in the Los Angeles Times, November 29, 1976, p. 1).

to identify two priority missions as:

* Survey and inventory the volume and distribution of surface and groundwater to assess available <u>supplies</u> for urban and agricultural consumption.

* Survey and monitor U.S. cropland to calculate long- and short-term <u>demand</u> for irrigation water.

Such information is incorporated into water supply and demand models which rely heavily on historical data and past trends in water supply and use.

The basic premise for utilizing remote sensing in acquisition of water demand information stems from the fact that several of the key parameters cannot be economically monitored on a seasonal or long-term basis without such technology. For example, water resource managers responsible for areas which are solely dependent on exotic water transported from other regions can easily predict next year's agricultural water demand by examining the present year's canal records. However, for areas dependent on both imported water <u>and</u> groundwater, managers have a difficult time assessing water demand because there is usually no way to accurately measure the amount of groundwater pumped. Consequently, canal records alone produce a serious underestimate of local water demand. If the aquifers being mined are continually lowering the water table, as is common in many western states, a serious overdraft situation may develop. Continuation of such practices could eventually lead to the regional depletion of an aquifer and subsequent loss of valuable agricultural production. Planned recharge of the aquifer through accurate long-term water demand predictions could rectify this situation. Remote sensing techniques can be used to inventory agricultural acreage. These data in conjunction with average irrigation rates can provide accurate multiple-year water demand predictions.

In the short-term, agricultural water demand information could be applied to seasonal intra-regional transport of water if a serious imbalance is identified in a geographic area. For example, a near real-time water demand estimate in May could alert water resource managers that new water demanding acreage has come into production in a region where previous groundwater mining had already lowered the water table. An administrative decision to acquire additional water from alternative sources could be made in order to maintain the groundwater level. An appropriate taxation schedule could also be applied to those users who continually mine groundwater and escape payment for transported water necessary to recharge the acquifer.

For several years prior to the TERRSE evaluation, NASA funded the University of California to develop remote sensing procedures to be used in

predicting water demand.[7] University researchers interfaced with California's local, regional and state agencies to document the accuracy and cost-effectiveness of remote sensing aided agricultural water demand predictions. These studies have focused on the identification of critical water demand parameters which can be inventoried by high altitude and LANDSAT analysis techniques. A study area in Kern County, California will be used to demonstrate, in a step-by-step manner, the application of remote sensing techniques to water demand prediction.

4.12 Kern County, California Water Demand Study Area

California contains approximately one quarter of all the irrigated land in the United States and the irrigation of these 8,000,000 acres accounts for more than 85% of the water used in California.[8] The State leads the nation in agricultural production with a gross crop value $4 billion annually, with another $2 billion in value-added by processing. These statistics provide ample testimony to the wealth producing ability of irrigated land in California.

As population figures continue to mount in this most populus of the 50 states, the water supply problem will be the same as it has been in the past; not of insufficiency, but maldistribution. About 75% of the State's precipitation and runoff occurs north of San Francisco, while about 75% of the need for and use of water occurs south of this point. The problem of maldistribution will continue to be solved by water transportation ... and eventually coordination with large scale desalinization projects when this technique becomes economically viable with the costs associated with future import developments.[9]

Kern County, California (Figure 4-2) is the second most productive agricultural county in the United States with an estimated value of direct farm marketing in 1975 of over $744,000,000. Production is primarily dependent on the irrigation of about 926,000 harvested acres (374,000 hectares).[10] Kern County consumed more than 820,000 acre-feet of California Aqueduct water in 1975 at a mean cost of $20 per acre-foot for the 16 county water districts. Groundwater in excess of two million acre-feet,

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7 Estes, John E., et al., "Water Demand Studies in Central California" in An Integrated Study of Earth Resources in the State of California Using Remote Sensing Techniques, Berkeley; University of California, Annual Progress Report, May 1976, pp. 3-10 to 3-23.

8 Irrigation Districts Association of California. California Water Resources Development (Irrigation Districts Association of Califonia: Sacramento, 1975).

9 Ibid.

10 Stockton, James, W., 1975 Annual Crop Report for the County of Kern. (U.S. Department of Agriculture, Bakersfield, 1976). pp. 1-8.

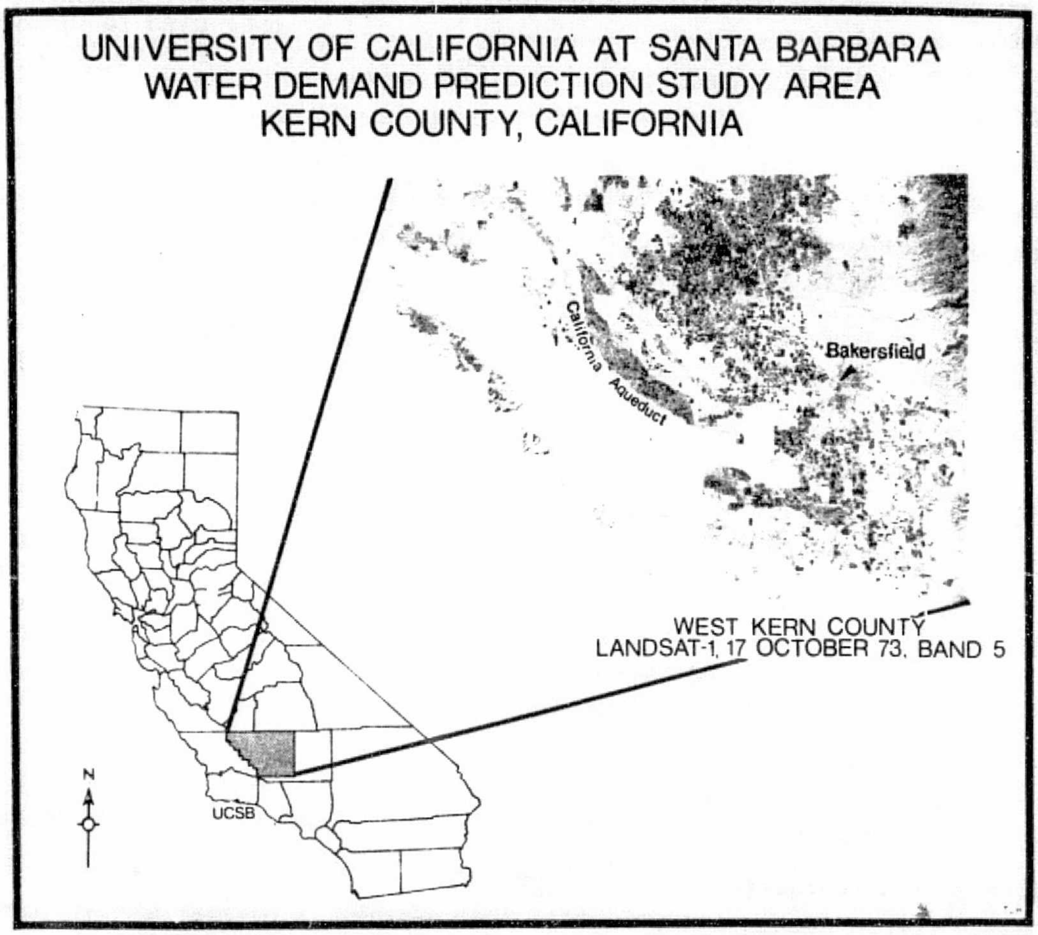

FIGURE 4-2. The agricultural water demand prediction study area in Kern County, California. Situated in the semi-arid southern part of the San Joaquin Valley, it is the second most productive agricultural county in the United States.

or four times that amount being imported by the state project, is extracted annually. Kern County's dependence on groundwater at rates exceeding a safe yield has resulted in a continuous decline of water table levels throughout most of the county.[11]

Analysis of projected California Water Project deliveries through 1990 indicate that irrigation water applied to crops and water used to replenish groundwater supplies account for approximately 85% and 10% of the Kern County water demand respectively. Urban-industrial and recreation demandsaccount for the remaining 5%. Even with the maximum supplies of imported state water contracted in 1990 (the actual need or demand for which will be realized as early as 1980) Kern County will continue to overdraft its basin if any expansion of irrigated agriculture occurs without additional importations.

In 1970, Kern County Water Agency (KCWA) developed a digital computer model of their groundwater basin.[12] The model was initially driven by historical data and relied heavily on agricultural landuse data derived from terrestrial surveys. The purpose of the model was total simulation of water transmission and storage throughout the Kern County water basin. Based upon an analysis of all model inputs, it was determined that remote sensing could provide data on several critical variables. The most dynamic variable in the model is the amount of irrigation water applied to agricultural lands. Water may either be pumped from local groundwater basins, lowering groundwater levels, or imported from other regions. Neither the amount of groundwater pumped nor the amount of irrigation water applied is known. Yet, accurate estimates for both are required as model inputs. The amount of water applied is best estimated from the total number of irrigated acres and the water requirements of the cropland under a given set of environmental conditions. The majority of remote sensing research in agricultural water demand modeling has been directed at providing this information.

Research on the development of remote sensing techniques for the generation of agricultural water demand information has lead to the remote sensing-user agency data flow illustrated in Figure 4-3. In this capacity, remotely sensed agricultural acreage data (i.e. croptype, fallow, double cropping, etc.) are extracted primarily from LANDSAT and high altitude imagery. The irrigation rates from ancillary sources may be refined through remote sensing (i.e. croptype, pre-irrigation, salinity leaching requirements, etc.). These two data sets are then interrogated to yield the output irrigation water demand prediction statistics. These statistics are

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[11] Kern County Water Agency, Annual Report - 1972 and 1973, KCWA, Bakersfield, 1974, p. 8.

[12] The Kern County Water Agency's groundwater model was developed by TEMPO, Center for Advanced Studies, Santa Barbara, California, a subsidary of General Electric.

used by the user agencies to optimize water management decisions. The following section discusses how one should proceed to empirically identify the major components of agricultural water demand for a given environment. Subsequent sections describe in a procedural manner, the specific aspects of remote sensing aided cropland and croptype inventories and the generation of water demand estimates. Cost estimates and equipment requirements are provided in Appendix I.

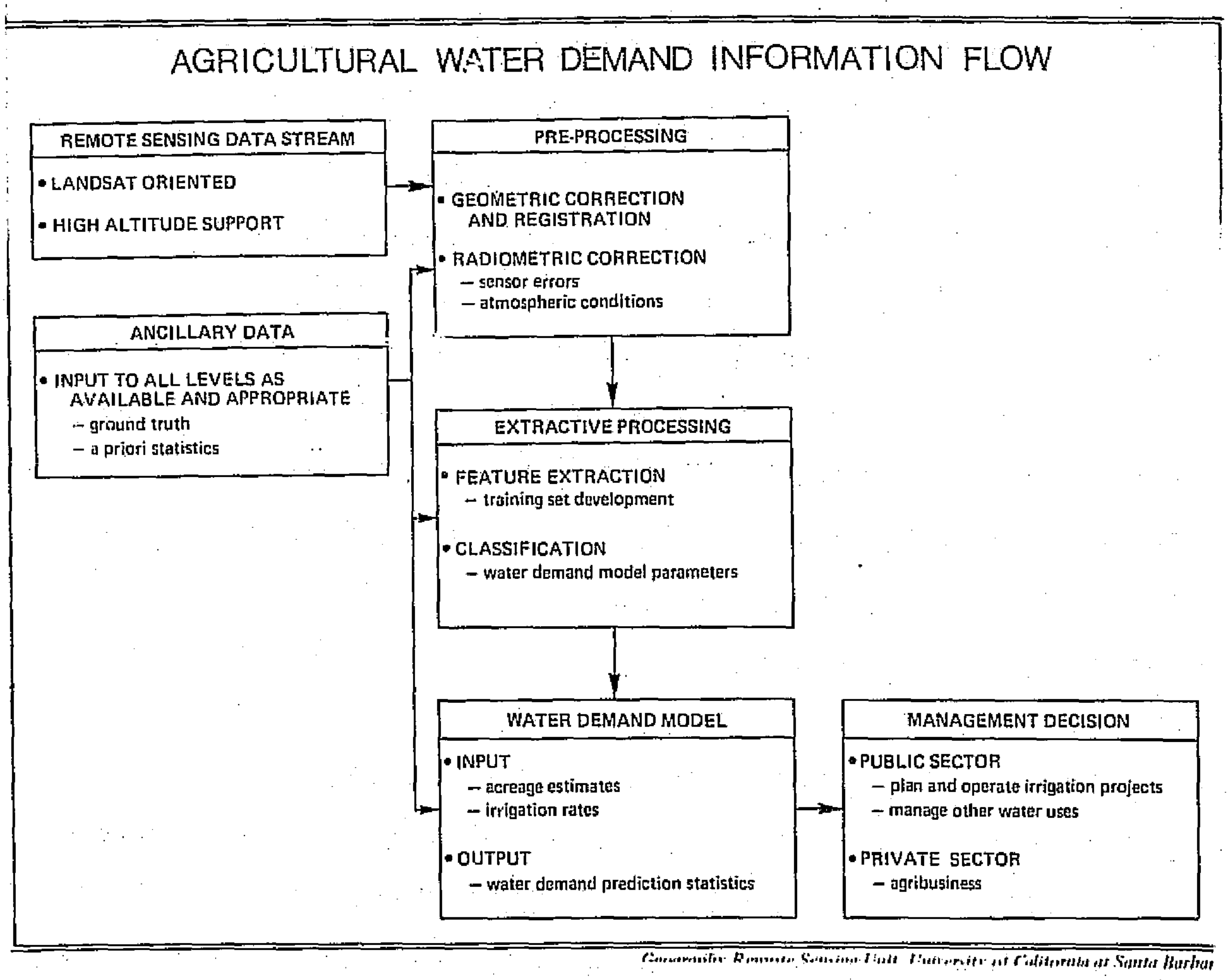


Figure 4-3. A diagrammatic representation of data flow through a remote sensing water demand prediction system. Once user information requirements are defined, the remote sensing data stream is processed (preprocessing and extractive processing) in conjunction with ancillary data to provide acreage and irrigation rate estimates. These basic inputs into the water demand prediction essentially drive the model. Water demand predictions are then used in both the public and private management decision sectors.

4 2 WATER DEMAND PREDICTION VARIABLES

4.21 Resolution of Prediction

Water demand predictions have both "spatial" and "temporal" resolutions, which means they pertain to a given area (a square mile, state, etc.) over specific time periods (monthly, yearly, etc.). In addition to spatial and temporal resolution, we may also consider a "categoric" resolution which specifies the level of information detail used in the classification scheme from which water demand predictions are derived, (e.g. irrigated vs. non-irrigated being general data, croptype data being more specific). The level of detail or specificity of a water demand prediction in each of these three dimensions will affect its utility as well as cost. In general, more specific data is both more useful and more costly. Planned and anticipated needs for water demand data should therefore be carefully examined on a case-by-case basis to match the resolution requirements of a specific application with appropriate procedures to acquire data at that detail. Spatial and temporal resolutions are usually well defined by the type of application. For example, water demand on a regional ten year basis may be adequate for general planning purposes while water demand on a yearly field-by-field basis may be required for specific canal routing or taxation purposes. Categoric resolution is usually governed by the need to achieve given accuracy levels. Even before specifying categoric resolution, however, it is necessary to select the appropriate categories or variables to be used in the water demand prediction. Figure 4-4 graphically illustrates those variables considered to be of importance to agricultural water demand prediction in the Southern San Joaquin Valley of California. It should be noted that there are two primary components of a water demand prediction, viz. acreage and irrigation rates. Each environment should be individually assessed in a similar manner when attempting a water demand prediction. Furthermore, it is necessary to perform this assessment in a quantitative manner, as will be discussed later using the Kern County example.

4.22 Kern County Example

In Kern County, California a need exists for yearly water demand data spatially aggregated to nodal polygons approximately three miles square. These data are used as input to a groundbasin hydrologic model. The total Kern County hydrologic system is both complex and dynamic. The KCWA groundbasis model must therefore incorporate detailed, yet relatively stable geologic information, in conjunction with constantly changing agricultural land use information. The most dynamic element of this system is the amount of irrigation water applied to agricultural lands. This water may either be pumped from local groundwater basins, with a negative impact on groundwater levels, or imported from other regions, thus potentially having a positive impact on local groundwater levels. At present, approximately 1,150,000 acre-feet of water is imported yearly through state and federal projects. However, since the exact amount of groundwater pumpage and irrigation water applied

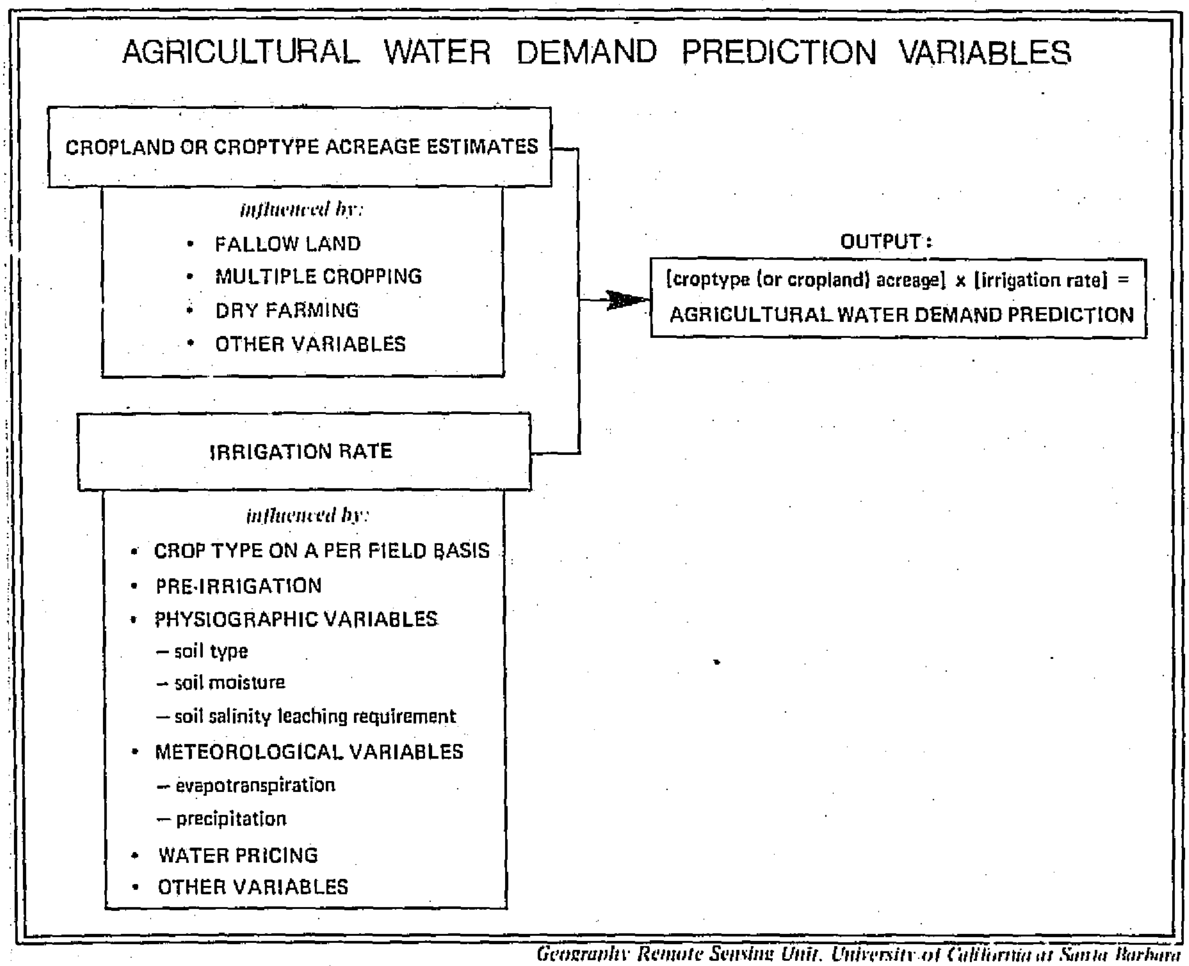


Figure 4-4. The range of variables considered to be of importance in determining agricultural water demand in the Southern San Joaquin Valley of California.

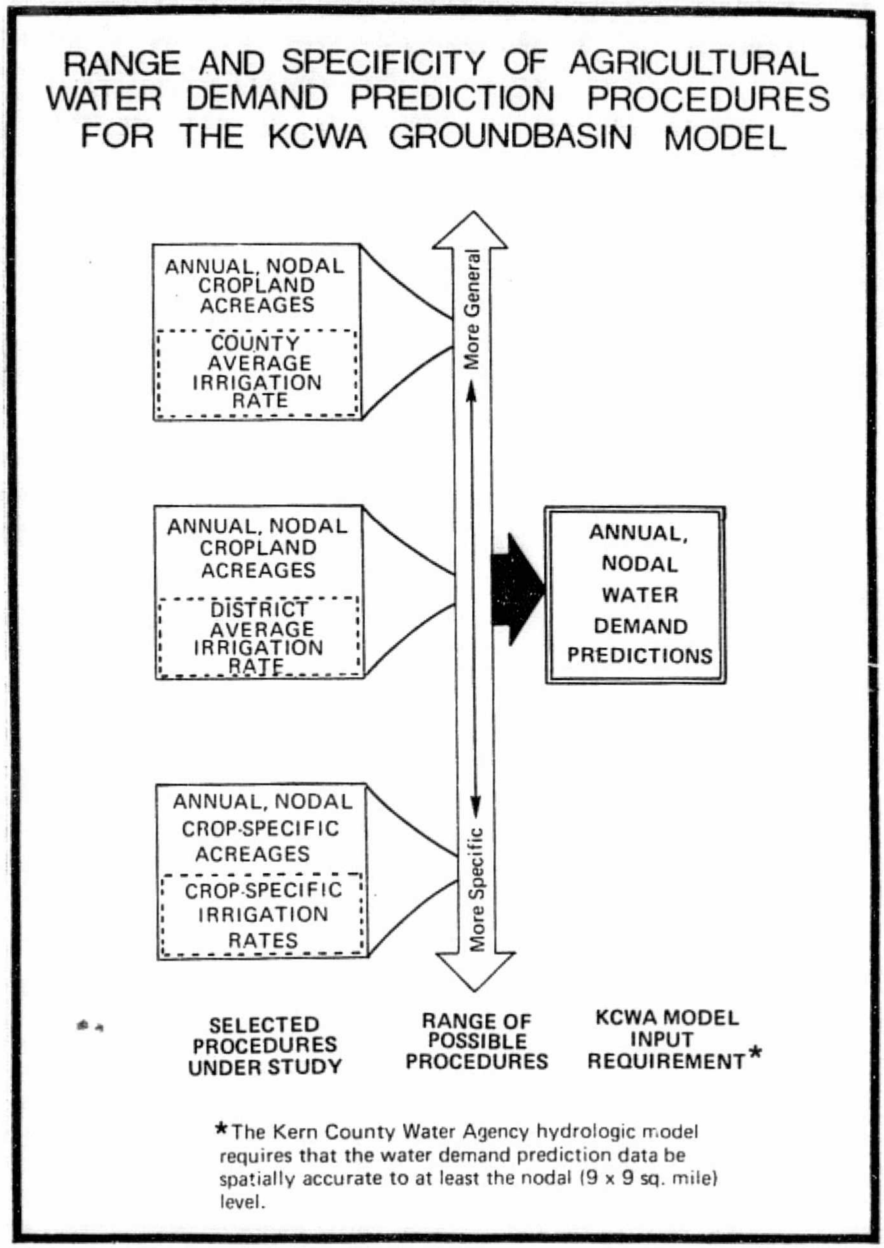
to the land is not known, accurate estimates for both of these quantities are required as model inputs. In areas where complete metering of groundwater pumpage is not available, as is common in Kern County, the total amount of applied water (i.e. demanded water) must be estimated by knowledge of irrigated acreages and water application rates. Even for this specific application there exists a wide spectrum of techniques which can be utilized to generate water demand predictions, as illustrated in Figure 4-5. These vary primarily according to the generality of the two primary inputs, i.e. acreage and application rate estimates. For the specific variables discussed in this report the two most extreme levels of input generality have been used. These levels entail irrigated cropland acreages and countywide average application rates for the most general approach, and croptype acreage and application rates as the most specific approach. It should be pointed out that the optimization of operational procedures may result in some intermediate approach.

Given that the spatial and temporal resolutions have been defined (nodal, yearly) it is possible to proceed to quantitative assessments of the impact of each major variable (refer back to Figure 4.4 for listing). Four major variables have been investigated to determine their impact in a large water district (Wheeler Ridge-Maricopa Water District) of Kern County. These variables have been selected for study because of their anticipated importance and/or their amenability to study using remote sensing techniques.

Each variable, i.e. croptype, fallow land, pre-irrigation, and double cropping, has been individually investigated to quantify the particular effect on the accuracy of its inclusion or exclusion in a water demand prediction procedure. For most variables, the effect on accuracy has been quantified for both of the two basic prediction methods, one using cropland data and the other utilizing croptype data.

The variations in accuracy due to the inclusion or exclusion of a variable in a specific water demand prediction using *croptype* data is quantified by comparing nodal croptype water demand predictions to the same predictions which have been improved through the consideration of the particular variable. For the purposes of comparison, the improved croptype prediction is assumed to be 100% correct. The difference in accuracy is calculated as the percent error of the prediction which did not consider the variable being investigated.

The difference in accuracy due to the inclusion or exclusion of a variable in a water demand prediction using *cropland* data is quantified in the following process: 1) The unimproved cropland prediction is compared to the improved croptype prediction. The latter prediction, as before, is assumed to be 100% correct. If the two predictions are compared the resulting improvement in accuracy is due not only to the inclusion of the variable in question, but also to the inclusion of croptype data. In order to separate the improvement due to croptype data, it is necessary to make an additional comparison.



Geography Remote Sensing Unit, University of California at Santa Barbara

Figure 4-5. The range of procedures from general to specific which may be employed to estimate nodal agricultural water demand in Kern County.

2) If an improved cropland prediction is compared to an improved croptype prediction, the resulting difference in accuracy is due to the inclusion of croptype data only. If this percent accuracy value is subtracted from the percent accuracy value resulting from the first comparison (unimproved cropland versus improved croptype prediction) the resulting difference is the change in accuracy caused by the inclusion of the variable in a cropland water demand prediction. Results are presented in Table 4-1.

TABLE 4-1

Summary Ranking of Water Demand Prediction Variables Investigated to Date and Their Influence on Nodal Water Demand Predictions in the Wheeler Ridge-Maricopa Water Storage District

Rank	Variable	Prediction Procedure	District-Wide Mean Nodal Increase in Water Demand Prediction Accuracy Due to Inclusion of the Variable (%)	Range of Nodal Errors (%)
1	Fallow Land	Cropland	7.9	0-75
		Croptype	8.0	0-98
2	Croptype	Cropland vs. Croptype	6.3	0-90
3	Multiple-Cropping	Cropland	2.8	0-19
		Croptype	3.6	0-16
4	Pre-Irrigation	Cropland	2.8	0-20
		Croptype	3.3	0-29

One of the most interesting effects noted in Table 4-1 is that produced by fallowing practices (8.0%), which exhibits a somewhat larger impact on water demand prediction accuracies than croptype data (6.3%). Since fallow land usually receives no irrigation, the rationale for its large impact is simple; its exclusion from models will result in over-estimations equal to the irrigation rate otherwise assumed. Also of major importance are the errors attributable to the lack of croptype data, which will be equal to the difference between the assumed irrigation rate and the true crop specific irrigation rate. Both fallow and croptype data were found to have two to three times the impact on water demand prediction accuracies when compared to multiple-cropping and pre-irrigation data. Of even greater importance is the larger range of potential nodal errors (nearly 5 times that of multiple-cropping and pre-irrigation) which are possible when crop-

type and fallow land data are not included in a prediction procedure.

This research was conducted to identify, in a quantitative manner, the individual effects of several variables on water demand predictions. Analyses were completed on a nodal basis using both of the major data gathering techniques, i.e. cropland and croptype inventories. This research is proving useful for determining the specific types of information necessary for accurate water demand predictions. From similar ranked variable lists, water resource managers may be able to design an optimum data collection system for their respective regions by selecting those components most responsible for maximizing accuracy levels.

It is important to remember that these variables are not necessarily independent, and any prediction procedure may incorporate one as a subset of another. For example, a thorough croptype inventory would be expected to include all four components, i.e. croptype, multiple-cropping, fallow and pre-irrigation data. The summary Table 4-1 thus documents only the individual impacts associated with each data component and suggests what types of data should be obtained.

4.3 PROCEDURAL MANUAL FOR USE IN REMOTE SENSING CROPLAND INFORMATION FOR WATER DEMAND PREDICTIONS

4.31 Introduction

The purpose of the procedures discussed in the previous section was to identify those specific types of information that should be incorporated into a water demand prediction procedure to achieve a desired accuracy level. When studied in conjunction with the feasibility and costs associated with their acquisition it should be possible to develop cost-effective procedures that meet specific applications requirements. An analysis of major water demand variables and acquisition costs may indicate that an adequate prediction can be generated from cropland data alone or cropland data at some basic level of refinement, e.g. by identification and subsequent subtraction of fallow acreage or addition of multiple-cropped acreage. This section will detail those procedural steps necessary to accomplish a cropland inventory, using as an example a region located in Kern County. As one might suspect, practical means for economically predicting water demand cannot be developed in isolation from the environmental characteristics of the region to which they are to be applied. Each location will possess some unique characteristics that might significantly affect the acquisition costs for each specific type of water demand information. Some examples of these characteristics include: cloud cover conditions (both daily and seasonally), field shapes and sizes, crop assemblage and relative proportions of each type, phenologies for each crop, local cultural practices (e.g. harvesting techniques, etc.), possible stratifications of the region into more homogenous sub-regions or "strata," and confusing "other" classes such as natural vegetation. Similarly, one cannot ignore the availability of various sources of remote sensing imagery, nor the suitability of each available type of

imagery for specific purposes. It is strongly recommended that a feasibility study or at least "trial run" of each procedure be accomplished before undertaking any single procedure on a large-scale basis. The following steps are therefore not offered in a rigid procedural format but rather act as a conceptual ordering of stages that should be undertaken only after all the interrelated aspects are properly understood.

4.32 Procedure

Step 1. *Acquisition of Suitable Imagery:* Acquiring suitable imagery is perhaps the most critical aspect of remotely mapping cropland acreage. Flying and developing costs associated with single purpose aircraft missions for croplands mapping often are prohibitively high. In addition to satellite imagery, several alternatives exist, including the acquisition of multi-purpose photography on a cost-sharing basis with those who might find such photography useful for other purposes. Care should be exercised, however, to ensure that such photography would adequately meet the requirements for cropland mapping. Some sources of multi-purpose photography are:

* Commercial firms that photograph large regions on a routine basis (e.g. yearly)

* NASA high altitude photography flown for various research institutions

* Various other service agencies (e.g. in the United States these include USDA-SCS and -SRS) that systematically inventory crop, soil, or water resources.

In assessing the value of these sources one should examine and weigh their relative merits on each of several grounds including:

1. The time frame for availability of the imagery (e.g. is it available monthly, annually, or only every five to ten years?). A crop calendar is helpful in matching availability to temporal requirements on a monthly or seasonal basis (crop calendar development is deferred here until the following section dealing with crop-type identifications).

2. The suitability of the scale and spatial resolution characteristics of the imagery for extracting needed cropland information.

3. The spectral characteristics of the imagery.

4. The costs associated with acquisition of the imagery.

5. The probability that continued acquisition of suitable imagery will be possible in the future, if needed.

Regardless of the source of the imagery, photographic transparencies are preferable to prints for the techniques discussed herein because of their high resolution characteristics. Figure 4.6 shows an example of multi-date LANDSAT multispectral imagery.

Step 2. *Acquisition of a Suitable Base Map:* A photogrametrically controlled (i.e., spatially accurate) base map is required to ensure that reliable croplands acreage statistics can be obtained from the mapped data. An accurate base map also ensures that information gathered in one year can be directly compared to that of other years. This map should include any features that will aid in the visual transfer of information from the imagery to a map, such as rivers, aqueducts, roads, and survey networks.

There are usually several sources of suitable base maps, most of which are governmental. Within the United States, examples include statewide planning agencies and various county departments such as assessor offices, water agencies, transportation departments, etc. The United States Geological Survey (USGS) topographic maps or their equivalent, especially those of scales smaller than 1:24,000, provide a nearly ubiquitous nation-wide base map source. Figure 4-7 is an example of a base map for Kern County.

Step 3. *Production of a Work Copy:* A work copy of the base map should be drafted or photographically created on frosted acetate or similar translucent material. This copy of pertinent base map features must be capable of accepting pencil annotations because croplands data to be acquired by image analysis will need to be annotated directly onto this copy. The purpose of the base map features (such as roads, etc.) is to allow simple orientation between the imagery and this work copy.

It is very useful to match the scale of the photography to that of the work copy. This allows the visual transfer of cropland detail to be accomplished with relative ease by direct overlay of the translucent map onto the photography. Standard tracing or lighted drafting tables provide the necessary illumination for examining the photography through the translucent base map.

If photographic prints must be used, either the work map needs to be nearly transparent, in which case pencil or even ink annotation is difficult, or other means must be used for simultaneously examining the work map and the photography. Various devices are available for this task, ranging from simple mirror stereoscopes to sophisticated optical transfer scopes.

Step 4. *Selection of a Suitable Classification Scheme and Subsequent Image Interpretation:* In developing such a scheme, the photo interpreter usually will need to work out with the potential user of the croplands map a compromise between (1) that which the user considers ideal for his purposes, and (2) that which the photo interpreter finds is consistently identifiable on the imagery which he must interpret. In some instances the development of a

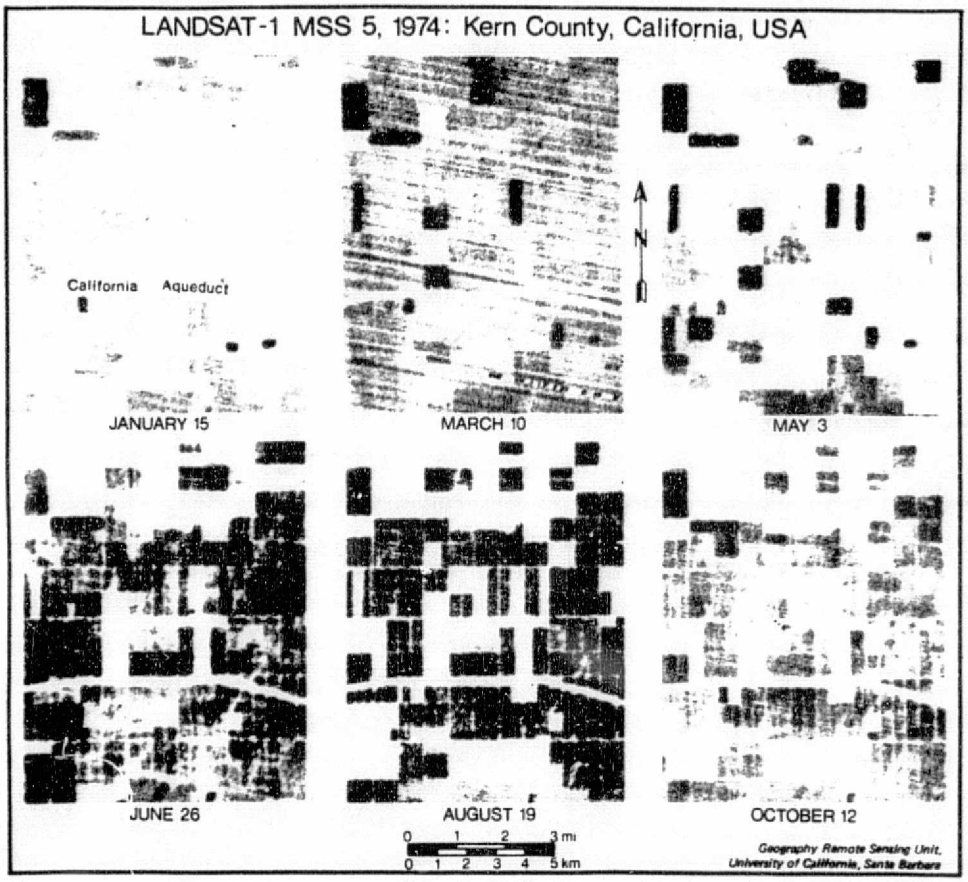


Figure 4-6. Six date sequence of LANDSAT-1 MSS band 5 imagery for a test site in Kern County, California. In this imagery healthy vegetation appears dark.

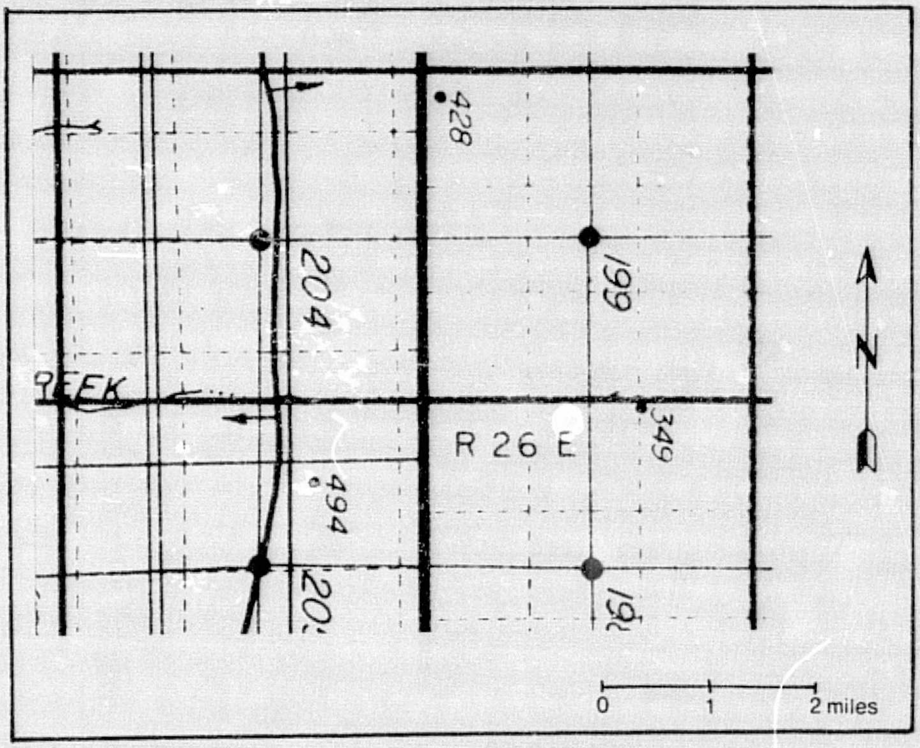


Figure 4-7. Pertinent detail in basemap, such as survey network, roads, canals, etc., allows rapid correlation of image information to a planimetric base. (Source: Kern County Water Agency — Polygonal Zones and Node Points.)

photo interpretation key to the classes that are to be identified should be undertaken at this point.

In those instances in which preliminary tests show that the necessary crop classification can be done from (multidate) LANDSAT imagery, great cost savings usually can be effected by the use of such imagery. Several approaches are available for the interpretation of croplands data from LANDSAT imagery. The approach followed will govern the amount and type of imagery acquired, type of work copy used, and image interpretation procedure. It has been found in numerous tests that mapping accuracies usually can be maximized by taking full advantage of sequential LANDSAT overpasses. When an adequate number of images are involved (such as monthly throughout the growing season), highest accrurcies seem possible using a simple dichotomous decision rule: i.e., on any given date of imagery, an actively growing crop is or is not visible. A significant advantage of this binary decision rule is that fallow or abandoned land can be removed from active cropland status. Fallow land, especially, is nearly impossible to identify on single date inventories. This simple dichotomous procedure requires only one LANDSAT MSS band, i.e., band 5, taken in the red spectral region (.6 to .7 μm). The combined orbits of LANDSAT's 1 and 2 presently offer the potential of 9-day coverage cycles, or approximately 40 imaging dates per year. The availability of such a large amount of coverage requires that a catalog be maintained of all available imagery. Microfilm browse files and a computerized geographic search service are available from the USGS Earth Resources Observation System (EROS) Data Center, Sioux Falls, South Dakota, and elsewhere. NASA publications are also available that specify geographic coordinates and image characteristics for each LANDSAT image created. These sources should be examined to determine frame number, cloud cover, and overall quality of each potential image. As with photography, LANDSAT image transparencies are generally preferable to prints for the techniques described herein because of their higher resolution.

When LANDSAT imagery is to be used, the scale and material used for the work copy will be dependent upon the technique used to transfer information (from image to map) and the interpretation scheme. Standard 1:1,000,000 scale LANDSAT imagery will, of course, require an 8X enlargement if 1:125,000 scale work maps are used. If the imagery is enlarged to 1:125,000 a frosted acetate work map is suitable since, as previously discussed, it is translucent and will accept penciled annotations. This work map can be placed upon the imagery and interpretations directly annotated upon the acetate. Alternatively, opaque material can be used for the map if other means are involved in correlating the image to map, such as a mirror stereoscope or optical transfer device.

When croplands information is being interpreted from LANDSAT imagery, the primary interpretive cues are grey level (or color if color composites are used) and field shape. In many regions, including the western two-thirds of the United States, for example, the interpretation and transfer tasks

are facilitated because field shapes are usually rectangular and in alignment with a systematically surveyed grid network. If the multidate MSS band 5 dichotomous procedure is used on any given date a field is classified as being "cropland" if it appears dark on MSS band 5 imagery on that date, indicating healthy vegetation. With some training the interpreter should be able to accurately distinguish between vegetated fields and natural vegetation, the former usually appearing more uniform and darker in tone than the latter. Since several images may be involved in each inventory it is necessary to verify and annotate each field as to its cropland status. It is sometimes best to begin a new work copy for each inventory. If possible, this work copy should indicate the previous status of all fields to assist the interpretation of questionable fields. Interpreters making use of color composite imagery should become familiar with all distinguishing stages of agricultural fields. These stages include freshly plowed, young crop, mature crop, dry crop (e.g., barley near harvest), defoliated crop (e.g. , cotton), and stubble or burned over conditions. Irrigation activities may also be noticeable on LANDSAT imagery during young crop stages.

Step 5. *Interpretation of the Photos and Annotation of the Base Map:* These two tasks usually are accomplished in concert. Since the tasks need to result in the production of accurate croplands information, they should be accomplished by someone familar with both the agricultural region and type of photography being used. While the work performed in this step typically is the most time-consuming, it merely employs the classification schemes and implements the procedures that have been described in the previous step. When several inventories are to be performed over a period of years different colors can be used to distinguish one inventory from another In this manner it is not necessary to completely redo each successive inventory. The work copy of the croplands map can be placed upon new photography, in which case only changes need to be annotated. This procedure allows for the simple production of change maps which depict only the changes in cropland acreage between any two inventory periods. Five or six inventories can be easily distinguished by proper color choice.

Step 6. *Production of the Final Copy of the Cropland Map:* Usually this copy should be made on drafting paper. It should have inked features and be suitable for blueline reproductions. An adhesive tone/pattern in the form of "press transfer" material can be used to delineate all cropland acreages. This material can simply be removed if the land should revert to non-cropland status. Updates of this map require only the addition or removal of pattern to those regions where the photo interpreter detects change. The legend of the final copy should clearly indicate all photography and/or imagery used in the composite cropland. Figure 4-8 is a final copy croplands map made from the six dates of LANDSAT imagery shown in Figure 4-6. Figure 4-9 is a final copy croplands map for the entire San Jaoquin Valley portion of Kern County.

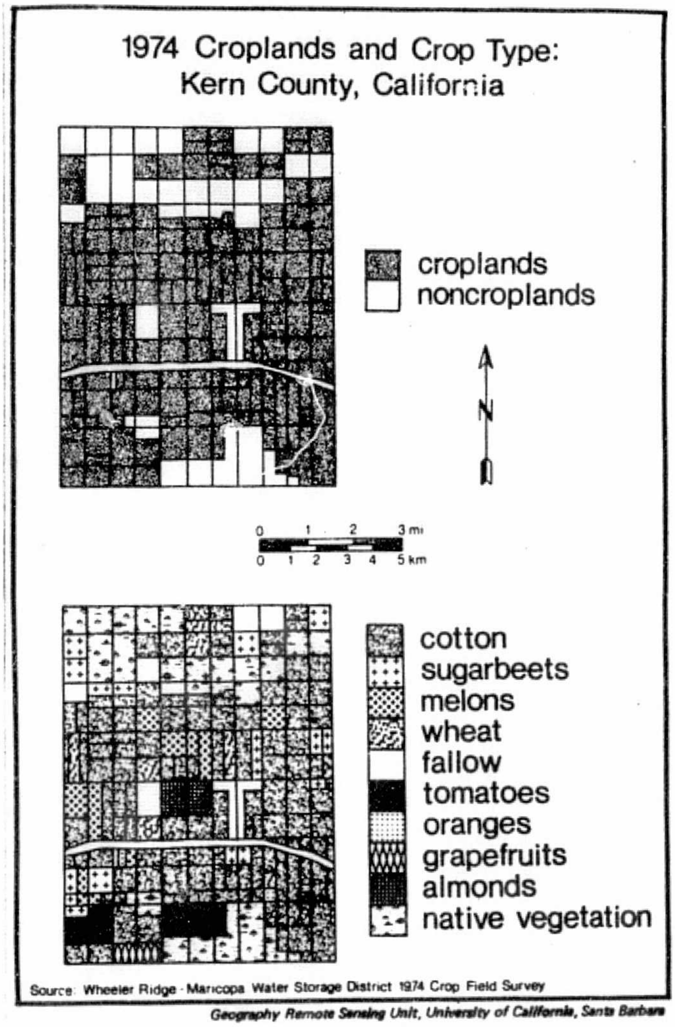


Figure 4-8. Upper portion is croplands data as interpreted from LANDSAT imagery in Figure 4-6. Lower portion shows same area as inventoried by field procedures, i.e. "windshield" survey.

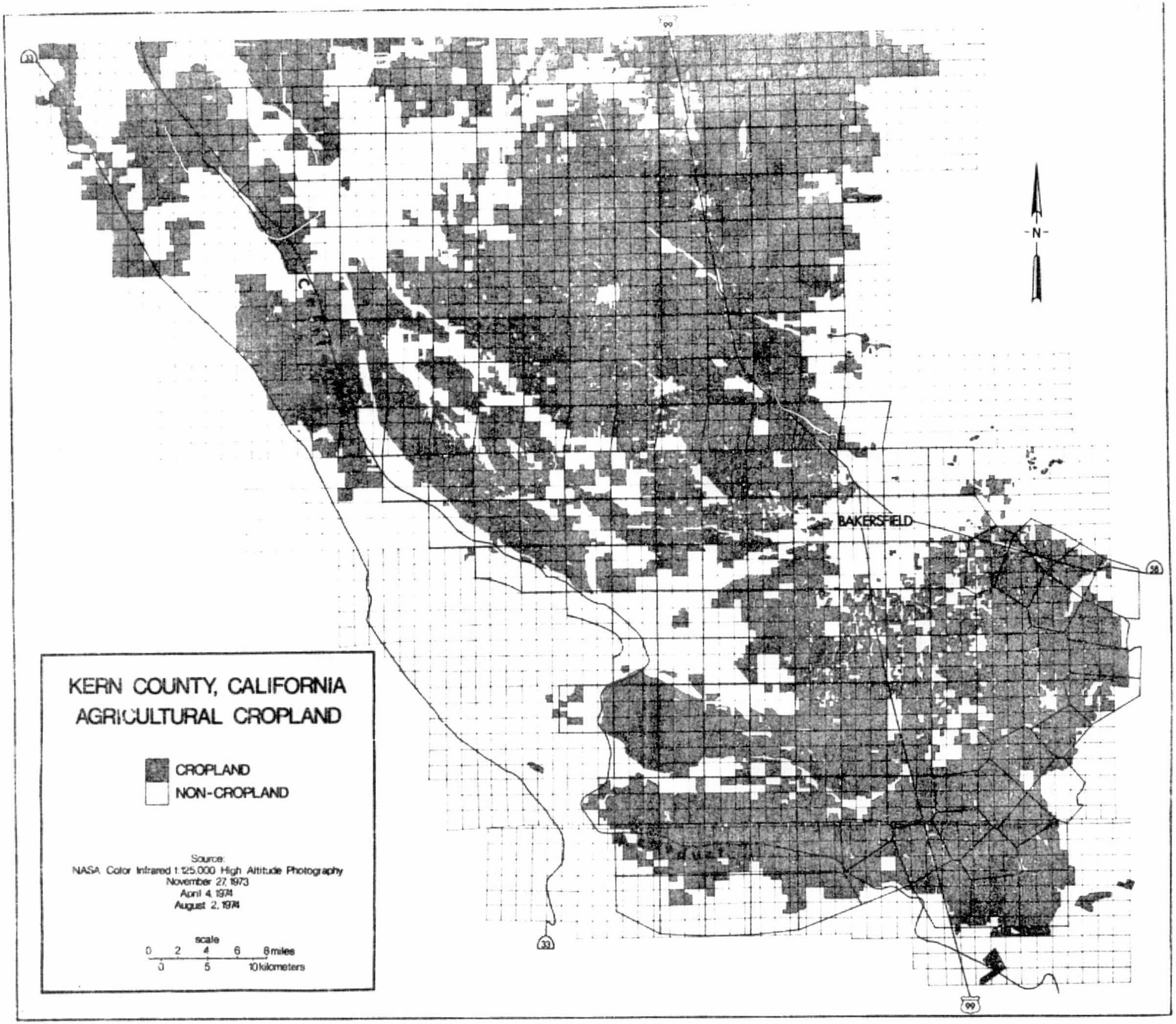


Figure 4-9. San Joaquin portion of Kern County as interpreted from multidate NASA high altitude photography. Original scale is 1:125,000.

Step 7. *Production of Various Reproduction Copies, as Required:* It is usually desirable to produce several blueline copies of each inventory. One should always be designated as the archive copy, since the final copy is continually updated. If it is necessary to produce a large number of copies, it is preferable to create a photographic transparency of each update; this transparency can serve both as an archive copy for future reference and as a master from which all blueline copies can be made, thereby saving the original. Photographic reproduction can always be used when it is necessary to enlarge or reduce the scale of the inventory map.

Step 8. *Proceed to the Making of Subsequent Analyses, as Appropriate:* Obviously a cropland map should rarely, if ever, be regarded as an end in itself. The ultimate usefulness of the procedure that has just been described normally will be found in the extent to which it facilitates, among other things: (A) the estimation of water demand, month-by-month and year-by-year, as imposed by those agricultural crops within the project area that are in need of irrigation; (B) a general approximation of agricultural yield in each portion of the area; and (C) the development of intelligent plans for future land use.

4.4 REMOTE SENSING CROP SPECIFIC INFORMATION FOR WATER DEMAND PREDICTIONS

4.41 Introduction

For many purposes it is not sufficient merely to determine, field-by field, whether crops are being grown. Instead, there is a need to know the specific type of crop. In contrast to the relatively simple croplands mapping procedure just discussed, crop identification requires a great deal of training and optimizing to maximize accuracies. On the plus side, crop-specific information allows more accurate water demand predictions and can be used in a greater variety of applications (such as agricultural reports, etc.). Axiomatically, the potentially wider audience increases the possibility of cooperative ventures to obtain such data.

The procedural manual will describe the following remote sensing approaches to obtaining crop specific information:

(A) Manual interpretation of multidate High Altitude color infrared photography (1:125,000) and enlarged LANDSAT (1:125,000) color composites.

(B) Digital classification of multidate LANDSAT computer compatible tapes (CCTs) using LARSYS[1] image processing software.

(C) Digital classification of multidate LANDSAT transparencies using a point densitometer and standard statistical analysis software.

These techniques represent a continuum from manual interpretation (A) requiring very modest resources, to the digital CCT method (B) which requires substantial hardware and programming expertise. The digital crop identification procedure based on manual point densitometer readings (C) is an intermmediate alternative available to those with access to modest densitometric equipment and standard statistical software packages. An agency should select that procedure which is most compatible with existing data requirements and agency resources. For the purposes of this procedural document, both the manual (A) and digital CCT method (B) are applied to a common 54 square mile study area in the Wheeler Ridge-Maricopa Water Storage District of Kern County, California. For comparative purposes the techniques are applied to similar temporal data sets.

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1 LARSYS is an acronym for a pattern recognition program developed by the Laboratory for Applications of Remote Sensing, Purdue University, Indiana.

Since these techniques require several of the same procedural steps it is instructive to analyze the procedures in unison. The last technique (C) based on point densitometry will be discussed separately.

4.42 Manual (A) and Digital CCT (B) Crop Identification Techniques: Image Inventory, Assessment, Acquisition and Formatting

Image Inventory: The cataloging of available imagery takes on added importance when specific crop identifications are undertaken. Final classification accuracies are very dependent upon the dates of imagery used since interpretations usually rely both upon the timing and sequence of stages that a field undergoes. In some instances imagery must be acquired during a limited time period when two otherwide indistinguishable crops may be correctly discriminated. The acquisition of both high altitude photography and LANDSAT imagery should first begin with a geographic search of EROS Data Center's image files. For example, for the 1974 growing season a search would provide most of the information shown in Table for the Wheeler Ridge-Maricopa study area.

Suitability and Acquisition: The suitability and subsequent purchase of imagery should be evaluated in terms of percent cloud cover, spectral and spatial resolution, and particularly the phenological make-up of the crop assemblage. If possible, a "browse" file should be consulted to view tentatively selected LANDSAT imagery. If this is not possible, a single LANDSAT channel from each date in transparency format aids in the selection of CCT's. For the high altitude photography, there is practically no way to detect cloud cover, color balance, or vignetting problems prior to the actual purchase.

Examination of Table 4-2 reveals that, for the Wheeler Ridge study, the LANDSAT digital CCT's were selected so as to be comparable with the high altitude data set. As these dates are spaced at approximately four month intervals throughout the 1974 growing season they represent a reasonable first-cut at multidate crop identification for the crop assemblage in the Southern San Joaquin Valley. A more rigorous method of selecting optimum LANDSAT channels for crop identification is introduced in the section on manual densitometry/digital classification.

Format: The high altitude color infrared photography and LANDSAT color composites (bands 4, 5, and 7) are purchased in positive, hard copy format for the manual crop identification procedures. An alternative approach for the creation of the LANDSAT color composites is to color combine the three channels either optically or photographically.

For the LANDSAT digital analysis the multidate CCTs must be geometrically rectified so that each date is mutually congruent with other (see Figure 4-10). This processing requires substantial image processing software. In this instance the Jet Propulsion Laboratory's VICARS software

Table 4-2. 1973 AND 1974 HIGH ALTITUDE AND LANDSAT IMAGERY

Available for the Wheeler Ridge-Maricopa Test Site

LANDSAT

	Date	Band Quality**	Cloud Cover	Suitability***
1.	11/04/73*	P P P P	10%	good
2.	11/22/73	G G G G	70%	unusable
3.	12/10/73	G G G G	10%	unusable
4.	12/28/73	G G G G	50%	unusable
5.	1/15/74	P P P P	0%	good
6.	2/02/74	P P - P	10%	good
7.	2/20/74	P P P P	0%	good
8.	3/10/74	P P P P	40%	good
9.	3/28/74	P P P P	60%	unusable
10.	4/15/74*	P P P P	10%	good
11.	5/03/74	G G G G	70%	good
12.	5/21/74	P G P P	0%	good
13.	6/08/74	P G G G	30%	good
14.	6/26/74	G G G P	0%	good
15.	7/14/74	P G G G	40%	not advisable
16.	8/01/74	G G P G	40%	good
17.	8/19/74*	P P P P	10%	good
18.	9/06/74	P P P G	40%	good
19.	9/24/74	G G G G	50%	good
20.	10/12/74	G G P P	30%	good
21.	10/30/74	- - - -	n.a.	no listing
22.	11/17/74	G G G -	40%	unusable
23.	12/05/74*	P P P G	10%	good
24.	12/23/74	F F F F	10%	good

HIGH ALTITUDE

	Date	Photographic Quality	Cloud Cover	Suitability
1.	11/27/73*	G	0%	good
2.	4/04/74*	G	0%	good
3.	8/15/74*	G	0%	good
4.	12/06/74*	F	0%	good

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* Indicates CCTs or high altitude photography purchased.

** MSS bands 4, 5, 6, and 7 respectively. Quality codes are G = good, F = fair, P = poor, - = not available

*** Suitability in terms of cloud-free test site coverage.

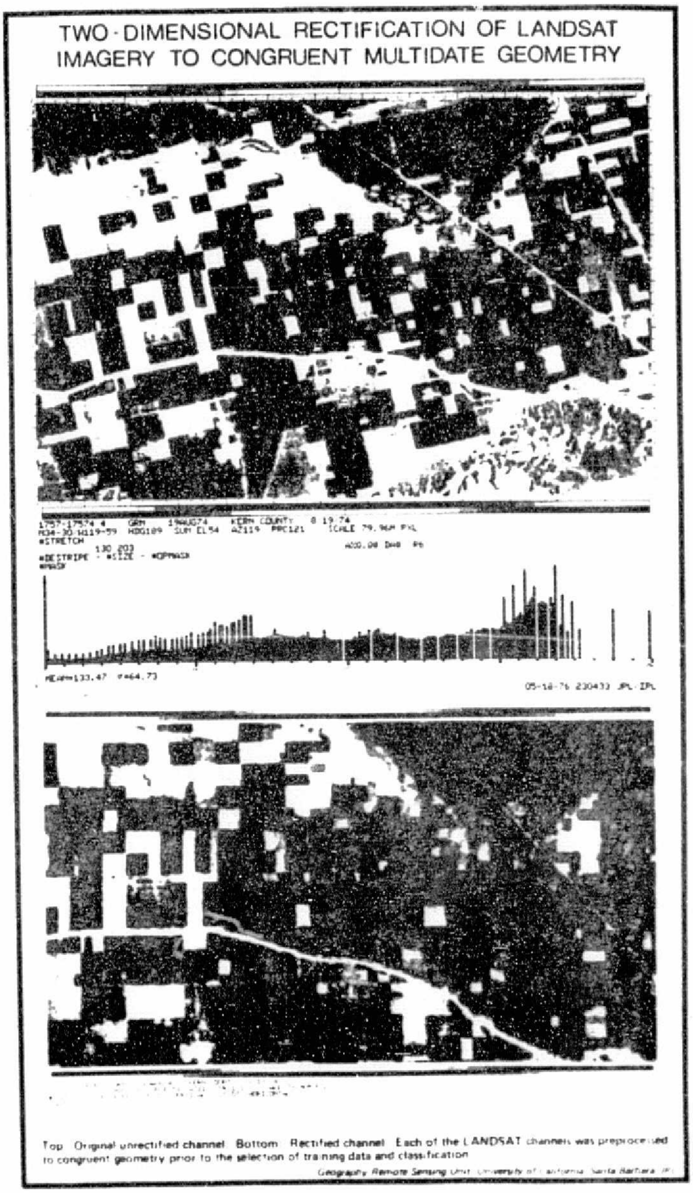

Figure 4-10. A comparison of unrectified (top) and rectified (bottom) Landsat images of the same area. For further explanation, see text.

was used to contrast stretch,[1] rectify, and in some cases spatially filter (fourier) the image (Figure 4-11). If image rectification is not possible, single date classifications might be attempted. However, satisfactory single date results are possible only if great care is taken in the evaluation of crop cycles.

4.43 Manual (A) and Digital CCT (B) Crop Identification Techniques: Ground Truth, Field Boundary Overlay and Crop Phenology Information

Ground Truth: A limited amount of field verified crop information is required for remote sensing crop identification procedures. This information is used to "train" the manual interpreter or digital classifier concerning the crop signatures in a specific region. It may also be used to assess "test" field classification accuracies.

When available, one should try to obtain the field verified data from existing sources. For our example, the Wheeler Ridge-Maricopa Water District provided 1974 spring and fall crop maps compiled for district planning purposes. These inventories were conducted by district personnel using standard terrestrial survey techniques. Based upon an analysis of this data in conjunction with the high altitude photography the study area was subdivided into three parts: a training area, an adjacent primary test area, and a more distant secondary test area for signature extension tests. The primary and secondary test area boundaries coincide with the 9 square mile "nodal" units of the KCWA hydrologic model. Specifically, the primary test area encompasses model nodes 197, 205, and 206 and the secondary test site encompasses nodes 198, 199, and 204 (see Figure 4-12).

When conducting ground truth surveys, limiting factors such as time and money usually preclude a complete inventory. Obviously, if it were economically possible to make a complete check there would be no need to use remote sensing to collect data. Sampling eliminates the necessity of doing a complete field check. It reduces costs, increases speed, and improves the accuracy of the limited amount of training and test data required. Obviously, such estimates are subject to error. Representative sampling errors must be small and the sample unbiased to achieve accurate results. When sampling a new environment of unknown characteristics the most reliable procedure is one which relies on a stratified systematic unaligned sample. An example is shown in Figure 4-13. The resulting sample combines the advantages of randomization and stratification with the useful aspects of systematic samples, while avoiding possibilities of bias because of possible periodicities.

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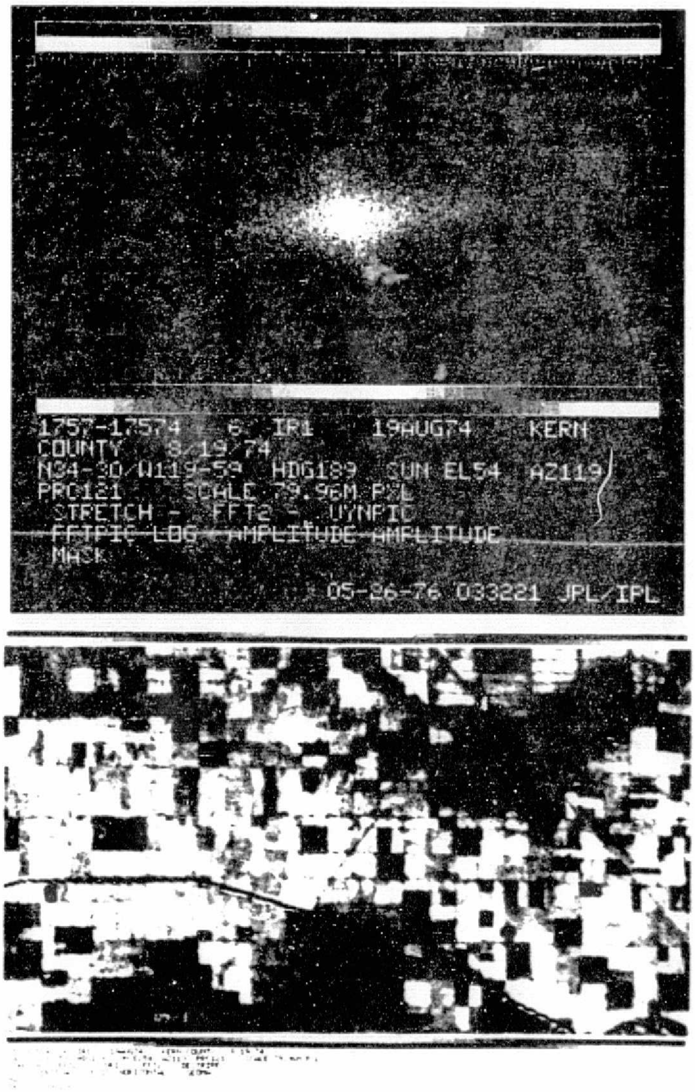
[1] GEOMA is the VICARS program used to rectify the LANDSAT channels to congruent geometry. VICARS is an acronym for Video Image Communication and Retrieval System.

FOURIER TRANSFORM OF LANDSAT (BAND 6)
AUGUST 19, 1974, IMAGERY



Each LANDSAT channel had fourier transform, contrast stretching, and geometric rectification image processing techniques applied.

Geography Remote Sensing Unit, University of California, Santa Barbara/JPL

Figure 4-11. Illustrated here is the result obtained when the VICARS software is used to rectify Landsat imagery.

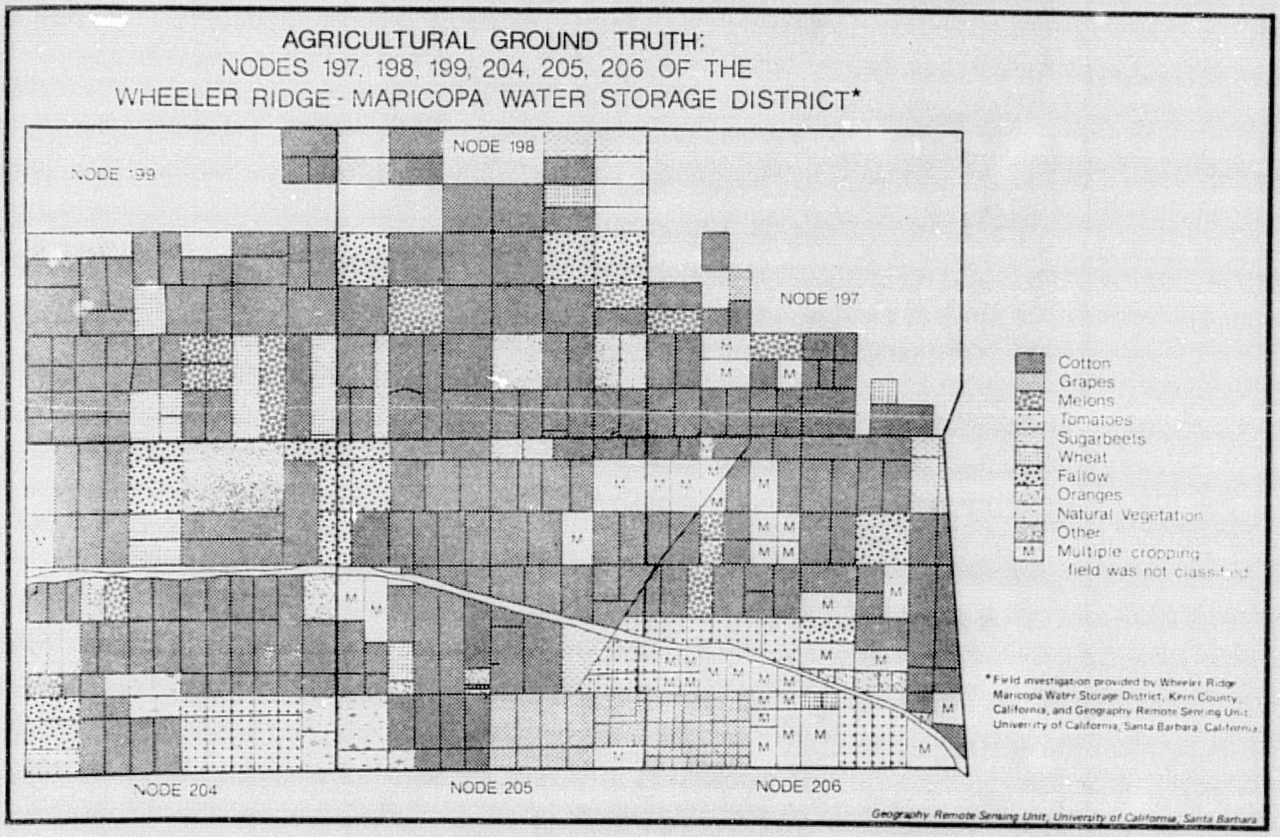


Figure 4-12. Agricultural Ground Truth provided by the Wheeler Ridge-Maricopa Water Storage District. This data was primarily used to assess classification accuracies. Additional similar information was used to select training fields.

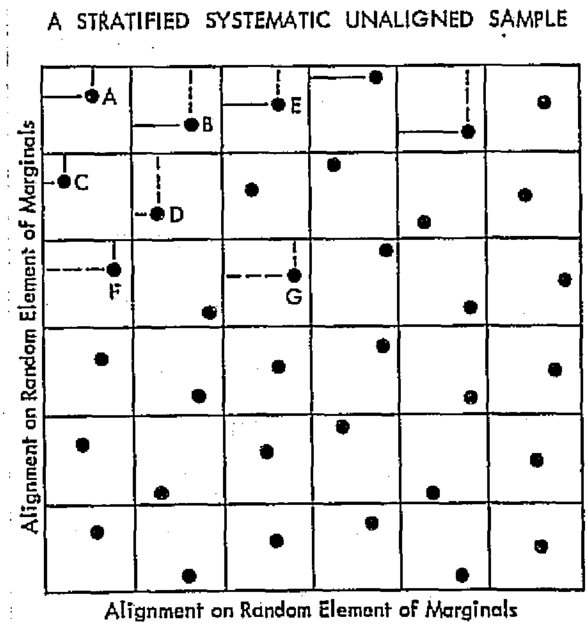


Figure 4-13. Example of a stratified systematic unaligned sample grid. First point A is selected at random and a given number of fields inventoried surrounding that point. The x coordinate of A is then used with a new random y coordinate to locate B, and a second random y coordinate to E, and so on across the top row of strata. By a similar process, the y coordinate of C and y coordinate of B are then used to locate D, of E and F to locate G, and so on until all crop classes have sufficient training elements. The number of sample elements should vary depending on the complexity of the original crop assemblage. The greater the number of different crop types, the larger the sample needs to be. Further information regarding this sample technique or others may be obtained from Sampling, Coding and Storing, Flood Plain Data by Brian J. L. Berry, Agricultural Handbook No. 237, Economic Research Service, United States Department of Agriculture.

Field Boundary Overlay: For the manual interpretation of both high altitude and LANDSAT false color imagery it is helpful to create a field boundary overlay of the training and test area (Figure 4-14). In this manner it is possible to keep an accurate account of individual field identifications and croptype for the selection of training fields and for the assessment of classification accuracies. These overlays are simple field boundary outlines extracted at contact scale (1:125,000) from the high altitude photography. Since it is recommended that LANDSAT color combined images be optically enlarged to this same scale the overlay may be used for both manual procedures.

Crop Phenology Information: As previously mentioned, the regional "crop calendar" is of primary importance when selecting dates of imagery to be used in a crop classification. This data is often available from existing sources. For example, the University of California Agricultural Extension Office in Bakersfield provided most of the crop calendar information in Table 4-3 . A monthly description identifies the phenological stages through which individual crops progress. Comments at the right of the table provide additional descriptive information on the appearance of each crop. *A priori* probabilities seen at the far left of the table are derived from 1973 crop acreage statistics for this region. The crop calendar and associated *a priori* probabilities represent the most important collateral information used by interpreters in the manual crop identification procedures.

4.44 Manual Crop Identification (A): Training Field Selection, Key Creation, Classification and Water Demand Prediction Results

Training Field Selection and Key Creation: Once the ground truth data, field boundary overlays, and multidate high altitude or LANDSAT imagery are available the training fields may be selected. During the selection procedure one should evaluate the ground truth and collateral information (e.g. crop specie, soils, etc.) to be certain that training data is selected from homogeneous "strata" representative of the test region. Ordinarily the training data is selected from areas which surround the test region. For both the LANDSAT and high altitude manual approach each training field is individually located, cut out, and placed into a key format as shown in Figure 4-15. Note that the training field number is found on the left with the four multidate images of each field appearing from left to right as they progress through the growing season.

Ideally, the crop key should be developed from the same imagery as that used by the interpreter in the test region classification. For example, the individual training fields in Figure 4-15 were extracted from the same high altitude photography used to produce the test region in Figure 4-16. This eliminates potential variations caused by atmospheric conditions or photographic processing that could create differences between the keys and imagery to be classified.

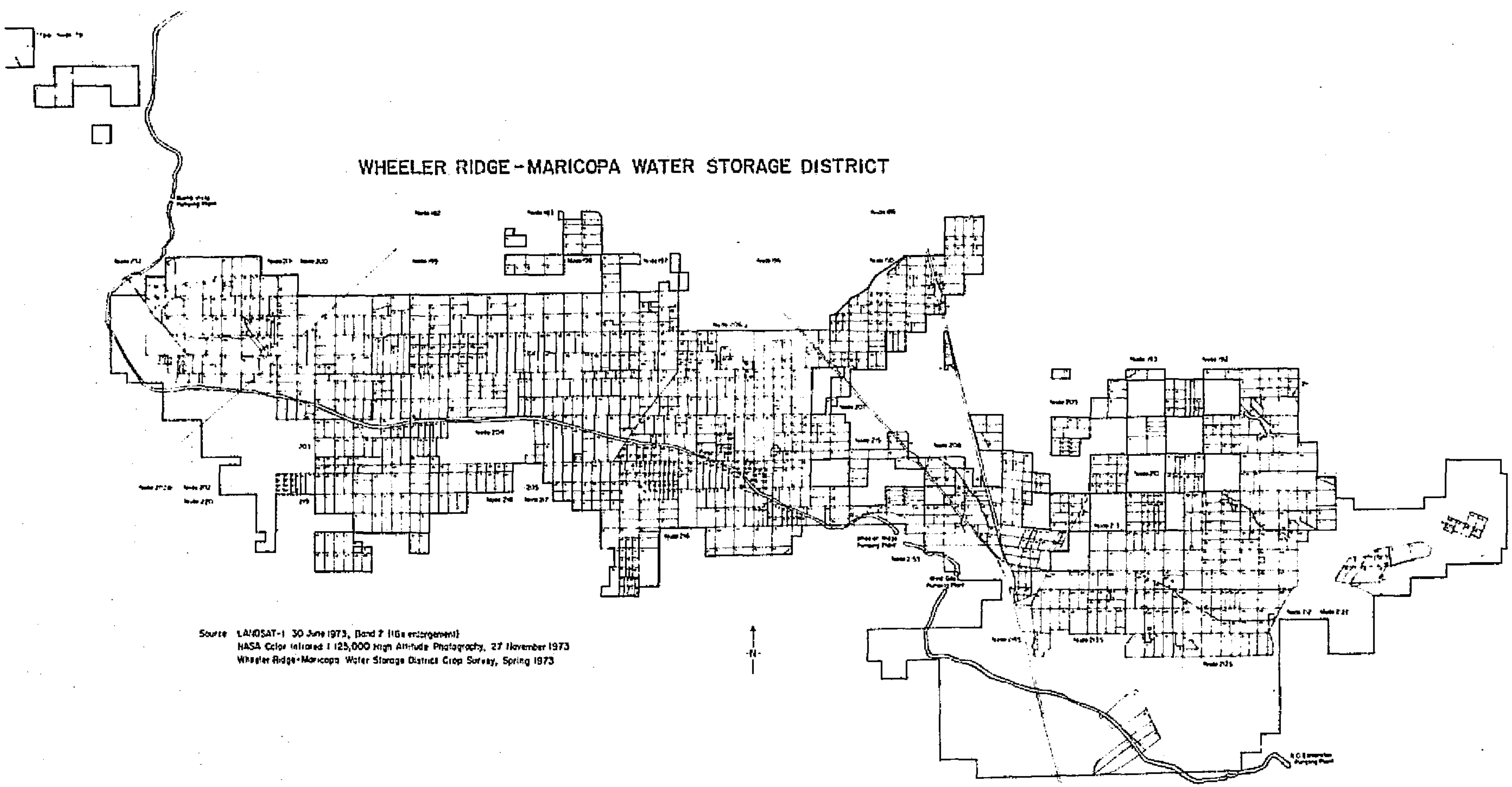


Figure 4-14. Field Boundary overlay of the Wheeler Ridge-Maricopa Water Storage District.

TABLE 4-3 .

PHENOLOGICAL CYCLE OF SELECTED CROPS IN THE SOUTHERN SAN JOAQUIN VALLEY PORTION OF KERN COUNTY, CALIFORNIA

Probability of Occurrence[a]	Crop Type	CROP CALENDAR 1973 N	1973 D	1974 J	F	M	A	M	J	J	A	S	O	N	D	REMARKS
52%	Cotton[+]	$\frac{D}{H}$	$\frac{D}{H}$/-	-	-	-	-/Y	Y/M	M	M	M	M/D	$\frac{D}{H}$	$\frac{D}{H}$	$\frac{D}{H}$/-	Cotton as bare soil in Mar & Apr; young in May & June; mature in July, Aug, Sept; defoliated in Sept & Oct; plowed under by Dec. 15.
9%	Grapes	M	-	-	-	-	-	Y	Y/M	M	M	M	M	M	-	Grapes depending on age will appear as bare soil in Apr; mature in Aug when field may have broad stripped look & still shows some degree of red to red black thru Nov & Dec
5%	Melons[+]	-	-	-	-	Y	Y/M	M	M	M/H	M/H/-	-	-	-	-	Apr image should appear as bare soil of young crop. Aug image will show a mature crop or bare soil signature. Nov & Dec signatures may be other crops; previously melons.
4.5%	Tomatoes[+] (spring)	-	-	-	Y	M	M	M	H	H	-	-	-	-	-	Signatures for spring tomatoes will be bare soil in Nov & Dec. Young crop in lightly rowed crop in Apr & Aug.
4.5%	Tomatoes[+] (fall)	M/H	-	-	-	-	-	-/Y	Y/M	M	M	M/H	M/H	M/H	-	Fall tomatoes will appear mature in Aug and show signs of crop in Nov & Dec & be bare soil in Apr.
3%	Lettuce[+]	-	-	-	-/Y	Y/M	M	H	H	-	-	-	-	-	-	Apr is the only date where lettuce fields should appear to be in crop
3%	Sugarbeets	-	-	-	-	Y	Y/M	M	M	H	H/-	-	-	-	-	Apr signature of sugarbeets should range between that of a young & mature crop. Other dates should appear as bare soil.
3%	Almonds	M/-	-	-	-	-	-/Y	Y	M	M	M	M	M	M/-	-	Most almonds here appear to have a bare soil signature for all dates except Nov when fields have reddish tinge.
3%	Small Grain[+*]	-	-	Y	Y	Y/M	M	M/H	H	H	S	S	S	-	-	Small grains will appear as mature crop in Apr; bare soil in other dates.
3%	Fallow	$\frac{BS}{S}$	$\frac{BS}{S}$	$\frac{BS}{S}$	$\frac{BS}{S}$	$\frac{BS}{S}$	$\frac{BS}{S}$	$\frac{BS}{S}$	$\frac{BS}{S}$	$\frac{BS}{S}$	$\frac{BS}{S}$	$\frac{BS}{S}$	$\frac{BS}{S}$	$\frac{BS}{S}$	$\frac{BS}{S}$	Will appear as a light bare soil signature on all dates.
2%	Natural Vegetation															Depending on area and date this signature may range from that of bare soil to a crop but will usually lack regular shape of a cultivated field.
1%	Oranges(young)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Will appear as a rowed field of young crops on all dates.

TABLE 4-3 (continued)

Probability of Occurrence[o]	Crop Type	1973 N	D	1974 J	F	M	A	M	J	J	A	S	O	N	D	
1%	Oranges (mature)	M	M	M	M	M	M	M	M	M	M	M	M	M	M	Signature will appear as a mature field on all dates; roving may or may not be evident.
1%	Peppers[+]	-	-	-	-/Y	Y/M	M	H	H	-	-	-	-	-	-	Peppers in image examples from this area appear mature in Nov. & bare soil on other dates.
1%	Onions	-	-	Y	Y/M	Y/M	M	M	H	H	H	-	-	-	-	Image examples of onions in this area appear as bare soil for all dates.
1%	Safflower[+]	-	-	-	-	-/Y	Y	M	M	H	H	-	-	-	-	Safflower appears as a young to mature crop in Apr and as bare soil on other dates.
1%	Plums	-	-	-	-	-	Y	Y	M	M	M	M	M/-	-	-	In this test area, plums appear dark in Aug and red to black on LANDSAT & a lightly roved pink on highflight all other dates.
1%	Potatoes[+]	-	-	Y	M	M	M/H	M/H	M/H	M/H	M/H/-	-	-	-	-	Potatoes will appear reddish in Apr; red to pink in Aug; other dates as bare soil.
.75%	Alfalfa(hay)	-	-	-	-	-/Y	M	$\frac{M}{H}$	$\frac{M}{H}$	$\frac{M}{H}$	$\frac{M}{H}$	$\frac{M}{H}$	$\frac{M}{H}$/-	-	-	Alfalfa appears as smooth, reddish tone on all dates of LANDSAT. On highflight, alfalfa appears pink to red vi-h a fine linear texture present.
.25%	Alfalfa(seed)	-	-	-	-	-	Y	M	M	M	H	H/-	-	-	-	

CROP CALENDAR

Bare Soil	-
Young Crop	Y
Mature Crop	M
Defoliated	D
Harvesting	H
Stubble	S

o Statistics for probability of occurrence are based on historical data and field verification information supplied by local water districts

/ denotes approximately one half month

$\frac{M}{H}$ this type of symbol indicates that although the crop is being harvested it may still appear mature

* small grain is used here to denote fields identified as wheat or barley

\+ denotes crops which are typically double cropped, that is a given field contains tomatoes in the spring and lettuce in the fall

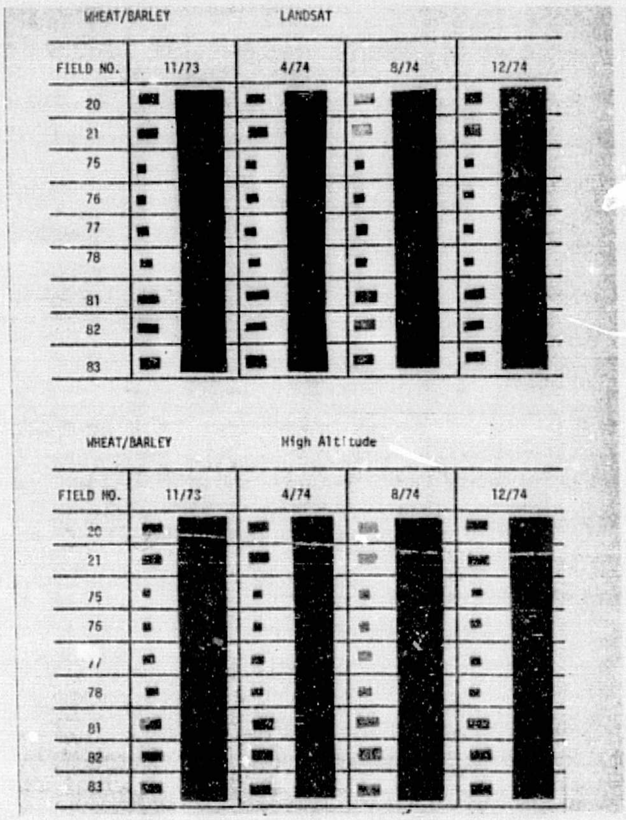


Figure 4-15. Example (reduced) of a wheat/barley image key for both the high altitude and LANDSAT manual crop identification procedures. FIELD NO. refers to the training field number from which each field was extracted. Note the slits which allow analysts to compare training fields with test fields. A key such as this is developed for each croptype in the study area.

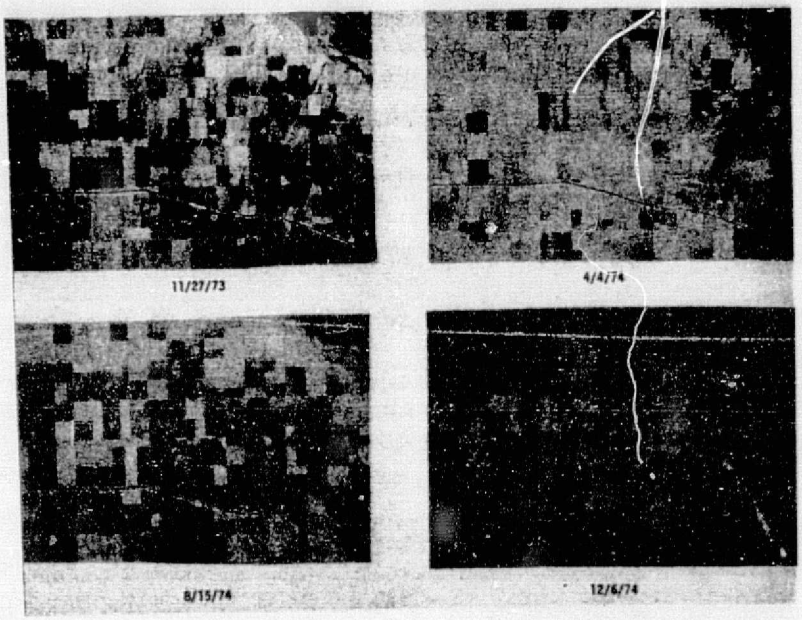


Figure 4-16. Test Region Color Infrared High Altitude Photography (original 1:125,000; here reduced) Wheeler Ridge-Maricopa Water District.

The key, along with the crop calendar previously discussed (refer to Table 4-3), comprise the training data for the manual interpretation methodology. Interpreters can use the image keys as overlay devices in order to match up a particular test field with what appears to be a similar croptype in the training field keys. Most interpreters work consecutively from node to node and from field to field in order to classify the test fields. Interpreters keep in mind the relative total acreage (frequency of occurrence) normally exhibited by each croptype within the project area when deciding upon the classification of a given field. This information is provided in the crop calendar (Table 4-3). Once the initial interpretation of the entire project area has been completed, a comparison of total assignments versus expected probabilities may lead to a revision of questionable classifications which can increase accuracies significantly.

Interpreted field croptypes may be annotated directly upon a work copy of the field boundary map or listed on answer sheets indexed by field identification codes. Answer sheets with each field's acreage included can be used quickly to transform specific crop application rates and acreages into water demand.

The cues used to manually identify each croptype will depend upon the crop signatures present, their relative proportions, the dates and quality of imagery used. Interpretation schemes can range from simple choices (such as "anything growing in January is a grain crop") to integrative, multidate decisions. Each environment must be individually assessed to optimize the interpretation scheme. The cost of acquiring the imagery, creating the keys, and typical interpretation time are presented in Appendix I.

Manual Crop Identification and Water Demand Prediction Results: Manual crop identification and water demand predictions presented in this manual are based on previous research which compared the effectiveness of LANDSAT versus high altitude techniques.[1] In this previous study eight trained image analysts took part in the manual crop identification, four examining high altitude photography and four the LANDSAT imagery. Results for only one of the four high altitude and LANDSAT interpreters will be discussed because a mean classification accuracy for four interpreters cannot be developed into an agricultural water demand prediction.

High Altitude: One interpreter's per field classification accuracies are reported in Table 4-4. Note that in this primary test region closest

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[1] Jensen, John R., Larry R. Tinney, and John E. Estes. "An Analysis of Manual and Digital Crop Identification Procedures Applied to High Altitude Photography and LANDSAT Multispectral Scanner Imagery." Scanner Versus Camera Evaluation. Pasadena: Jet Propulsion Laboratory (January, 1977), (in press).

Table 4-4

MANUAL HIGH ALTITUDE PER FIELD CROP CLASSIFICATION:
NODES 197, 205, 206 OF THE WHEELER RIDGE-MARICOPA WATER STORAGE DISTRICT, 1974

DISTRICT GROUND TRUTH \ RS CLASSIFICATION	% ACCURACY	COTTON	GRAPES	MELONS	TOMATOES	SUGARBEETS	WHEAT	FALLOW	ORANGES	NATURAL VEGETATION	OTHER	TOTAL
COTTON	99	99	2	3			3				3	110
GRAPES	86	8	48									56
MELONS	0	4	1									5
TOMATOES	59	4			10						3	17
SUGARBEETS	0	2	1	1	1							5
WHEAT	25	1					1				2	4
FALLOW	0	2		3	1							6
ORANGES	0										9	9
NATURAL VEGETATION	100									2		2
OTHER	33		4	1		1	4				5	15
TOTAL	72	120	56	8	12	1	8	0	0	2	22	165 \ 229

Table 4-5

MANUAL HIGH ALTITUDE ACREAGE WEIGHTED CROP CLASSIFICATION AND WATER DEMAND PREDICTION:
NODES 197, 205, 206 OF THE WHEELER RIDGE-MARICOPA WATER STORAGE DISTRICT, 1974

DISTRICT GROUND TRUTH (AC.) \ RS CLASSIFICATION (AC.)	% ACCURACY	COTTON	GRAPES	MELONS	TOMATOES	SUGARBEETS	WHEAT	FALLOW	ORANGES	NATURAL VEGETATION	OTHER	TOTAL
COTTON	92	6635	90	100			285				120	7230
GRAPES	59	480	680									1160
MELONS	0	260	80									340
TOMATOES	45	280			314						110	704
SUGARBEETS	0	95	80	30	125							330
WHEAT	32	40					50				65	155
FALLOW	0	200		200	60							500
ORANGES	0										195	195
NATURAL VEGETATION	100									260		260
OTHER	38		200	15		40	330				360	945
TOTAL	71	7390	1130	365	519	40	665	0	0	260	850	8319 \ 11639
RS WATER DEMAND PREDICTION acre feet ABS \ REL	98 \ 73	26567 \ 21635	2503 \ 2193	1095 \ 0	1557 \ 942	140 \ 0	731 \ 55	0 \ 0	0 \ 0	0 \ 0	2973 \ 1210	35266 \ 26217
DISTRICT TRUTH	100	23359	3596	1020	2112	1155	171	0	565	0	3134	35632

Table 4-6

CROP SPECIFIC IRRIGATION RATES
WHEELER RIDGE – MARICOPA WATER STORAGE DISTRICT, 1974

COTTON	3.3	ACRE FEET
GRAPES	3.1	
MELONS	3.0	
TOMATOES	3.0	
SUGARBEETS	3.5	
WHEAT	1.1	
FALLOW	0	
ORANGES	3.0	
NATURAL VEGETATION	0	
DISTRICT AVERAGE	3.38	

to the training data the interpreter correctly identified 90% of the cotton, 80% of the grapes, and 59% of the tomatoes which account for most of the acreage. By acreage weighting each of the classified fields and multiplying by its appropriate crop specific irrigation rate (refer to Table 4-5) a 73% absolute water demand prediction is obtained compared to water district records.

Examination of Table 4-7 reveals that for the secondary test area (nodes 198, 199, 204) located further from the training data, the interpreter achieved a 63% acreage weighted crop identification accruacy, a drop of 9% yielding a 65% accurate water demand prediction (Table 4-8). This drop in classification accuracy going from the primary to the secondary test region is mainly attributed to vignetting in the original high altitude photography. Both the training and primary test regions were located near the border of the 9 x 9" photography on two dates causing these regions to image darker. The secondary area in this photography was located near the principle point resulting in normal color balance and contrast. Consequently, when conducting manual high altitude crop inventories be certain to either process the photography with an anti-vignetting filter or stratify training and test regions with this constraint in mind. Vignetting is a common problem and could significantly lower classification and water demand prediction accuracies as demonstrated.

Table 4-9 is a summary of both the primary and secondary test area acreage weighted crop classification and water demand predictions. Overall, the 66% acreage weighted crop identification yielded a 70% <u>absolute</u> water demand prediction. An important statistic to consider is the 98% <u>relative</u> water demand accuracy. The high accuracy is the result of acreages in one crop class being misclassified into another crop class with an approximately equal irrigation rate. For example, Table reveals that melons, tomatoes, and oranges have water application rates of 3 acre-ft./year^{-1}. Any misclassification among the three categories will not affect the relative water demand prediction. This suggests that users should carefully evaluate their individual situations to determine if crop groups might be more easily identifiable than specific crops.

<u>LANDSAT</u>: Manual crop identification and water demand prediction using LANDSAT color composites proved slightly superior yet not significantly different than the high altitude techniques.[1] For example, one interpreter's

[1] To determine if there was a statistically significant difference between the LANDSAT and high altitude techniques, previous research applied a t-test to eight individual analysts' results on a nodal basis. This test is specifically designed for small sample data sets. This analysis concluded that there was no statistically significant difference between the manual high altitude and LANDSAT approaches for crop identification (t = .505; 2.07 required for .05 level of significance).

Table 4-7

MANUAL HIGH ALTITUDE PER FIELD CROP CLASSIFICATION: NODES [illegible], [illegible], [illegible] OF THE WHEELER RIDGE MARICOPA WATER STORAGE DISTRICT, 1976

DISTRICT GROUND TRUTH \ RS CLASSIFICATION	% ACCURACY	COTTON	GRAPES	MELONS	TOMATOES	SUGARBEETS	WHEAT	FALLOW	ORANGES	NATURAL VEGETATION	OTHER	TOTAL
COTTON	81	90	5	2	8	1					5	111
GRAPES	0										1	1
MELONS	0	3			2					1	3	9
TOMATOES	0		1	10								11
SUGARBEETS	50	1			3	4						8
WHEAT	78				1		7				1	9
FALLOW	33	1	2	1				2				6
ORANGES	0										1	1
NATURAL VEGETATION	100									5		5
OTHER	5	2	15							1	1	19
TOTAL	60	97	23	13	14	5	7	2	0	7	12	109 / 179

Table 4-8

MANUAL HIGH ALTITUDE ACREAGE WEIGHTED CROP CLASSIFICATION AND WATER DEMAND PREDICTION: NODES [illegible], [illegible], [illegible] OF THE WHEELER RIDGE MARICOPA WATER STORAGE DISTRICT, 1976

DISTRICT GROUND TRUTH (AC.) \ RS CLASSIFICATION (AC.)	% ACCURACY	COTTON	GRAPES	MELONS	TOMATOES	SUGARBEETS	WHEAT	FALLOW	ORANGES	NATURAL VEGETATION	OTHER	TOTAL
COTTON	80	7035	390	310	640	100					320	8795
GRAPES	0										15	15
MELONS	0	400			80					60	140	680
TOMATOES	0		80	600								680
SUGARBEETS	53	100			180	320						600
WHEAT	70				110		440				80	630
FALLOW	13	160	335	25				80				600
ORANGES	0										45	45
NATURAL VEGETATION	100									320		320
OTHER	22	160	565							60	215	1000
TOTAL	63	7855	1370	935	1010	420	440	80	0	[illegible]	915	8410 / 13365
RS WATER DEMAND PREDICTION (acre feet) ABS \ REL	93 \ 65	25922 \ 23215	4247 \ 0	2805 \ 0	3030 \ 0	1470 \ 1120	484 \ 484	0 \ 0	0 \ 0	0 \ 0	2755 \ 727	40713 \ 25546
DISTRICT TRUTH	100	29024	47	2040	2040	2100	693	0	135	0	3380	39459

Table 4-9

MANUAL HIGH ALTITUDE ACREAGE WEIGHTED CROP CLASSIFICATION AND WATER DEMAND PREDICTION: NODES 197, 196, 199, 204, 205, 206 OF THE WHEELER RIDGE-MARICOPA WATER STORAGE DISTRICT, 1974

R.S. CLASSIFICATION (AC.) \ DISTRICT GROUND TRUTH (AC.)	% ACCURACY	COTTON	GRAPES	MELONS	TOMATOES	SUGARBEETS	WHEAT	FALLOW	ORANGES	NATURAL VEGETATION	OTHER	TOTAL
COTTON	85	13670	480	410	640	100	285				440	16025
GRAPES	53	460	660								15	1175
MELONS	0	650	80		80					60	140	1020
TOMATOES	23	280	80	600	314						110	1384
SUGARBEETS	34	195	80	30	305	320						930
WHEAT	62	40			110		490				145	785
FALLOW	7	360	335	245	80			80				1100
ORANGES	0										240	240
NATURAL VEGETATION	100									600		600
OTHER	30	160	765	15		40	330			60	575	1945
TOTAL	65	15845	2500	1300	1529	460	1105	80	0	720	1665	16729 \ 25204
R.S. WATER DEMAND PREDICTION (acre feet) ABS \ REL	98 \ 70	52289 \ 45111	7750 \ 2108	3900 \ 0	4587 \ 942	1610 \ 1120	1216 \ 539	0 \ 0	0 \ 0	0 \ 0	5628 \ 1926	76980 \ 51746
DISTRICT TRUTH	100	52883	3643	3060	4152	3255	864	0	720	0	6574	75151

LANDSAT results for the primary test area (Table 4-10) reveal a 4% increase in crop identification and 5% increase in water demand prediction accuracy for the primary test region (Table 4-11). As in the high altitude technique accurate cotton and grape classification were very important.

The manual interpretation of LANDSAT imagery also experienced a drop in classification accuracy as analysts moved from the primary to the secondary test regions. For example, the interpreter under consideration dropped 6% in acreage weighted crop identification accuracy (76% to 70%; Tables 4-11 and 4-13). The decrease in accuracy for both manual techniques suggests that, in addition to the vignetting which is known to be a factor in the high altitude procedure, some inherent difference between the sites may be responsible. For example, soil type variation such as the increasing occurrence of salt-affected soils in the secondary test site is but one environmental parameter that could be contributing to the signature extension problem.

Table 4-14 reports the total primary and secondary LANDSAT acreage weighted crop identification and water demand prediction accuracies. Note that the 73% crop classification accuracy resulted in a 73% accurate absolute and a 94% relative water demand prediction. As discussed in the high altitude procedure, a crop grouping procedure might capitalize on the relative water demand prediction accuracies.

The manual LANDSAT technique described here has been developed for large scale irrigated agriculture in an arid environment, specifically Kern County in California. Other environments may not find the present 80m ground resolution of LANDSAT adequate because of smaller or more irregularly shaped fields. In general, the manual technique as discussed does not appear to be reliable for fields that are less than 20 acres in size.

4.45 Digital LANDSAT Crop Identification: Training and Test Field Selection, Channel Selection, Classification and Water Demand Prediction Results.

Training and Test Field Selection: Manual stratification of training and test field regions should occur in the manner described in the manual high altitude and LANDSAT procedures. In addition to the manual stratification, however, a "clustering"[1] analysis of the digital data will provide optimum discrimination of homogeneous classes

[1] Clustering is a LARSYS subroutine.

Table 4-10

MANUAL LANDSAT COLOR COMPOSITE PER FIELD CROP CLASSIFICATION: NODES 197, 205, 206 OF THE WHEELER RIDGE-MARICOPA WATER STORAGE DISTRICT, 1974

DISTRICT GROUND TRUTH \ RS CLASSIFICATION	% ACCURACY	COTTON	GRAPES	MELONS	TOMATOES	SUGARBEETS	WHEAT	FALLOW	ORANGES	NATURAL VEGETATION	OTHER	TOTAL
COTTON	90	99	4	2	1	1	1	2				110
GRAPES	84	7	47					1			1	56
MELONS	0	3	1								1	5
TOMATOES	0	4	8			3		1			1	17
SUGARBEETS	20	2				1		1			1	5
WHEAT	50						2				2	4
FALLOW	67	1						4			1	6
ORANGES	89		1						8			9
NATURAL VEGETATION	100									2		2
OTHER	67	2					1	2			10	15
TOTAL	76	118	61	2	1	5	4	11	8	2	17	173 / 229

Table 4-11

MANUAL LANDSAT COLOR COMPOSITE ACREAGE WEIGHTED CROP CLASSIFICATION AND WATER DEMAND PREDICTION: NODES 197, 205, 206 OF THE WHEELER RIDGE-MARICOPA WATER STORAGE DISTRICT, 1974

DISTRICT GROUND TRUTH (AC.) \ RS CLASSIFICATION (AC.)	% ACCURACY	COTTON	GRAPES	MELONS	TOMATOES	SUGARBEETS	WHEAT	FALLOW	ORANGES	NATURAL VEGETATION	OTHER	TOTAL
COTTON	92	6630	170	100	120	40	125	45				7230
GRAPES	80	140	930					50			40	1160
MELONS	0	180	60								80	340
TOMATOES	0	125	292			185		90			12	704
SUGARBEETS	32	115				105		80			30	330
WHEAT	58						90				65	155
FALLOW	44	120						220			160	500
ORANGES	79		40						155			195
NATURAL VEGETATION	100									280		280
OTHER	65	55					160	120			610	945
TOTAL	76	7365	1512	100	120	330	375	605	155	280	997	9020 / 11839
R.S. WATER DEMAND PREDICTION [illegible] ABS \ REL	58 / 78	24305 / 21879	4687 / 2383	300 / 0	330 / 0	1155 / 315	412 / 99	0 / 0	465 / 465	0 / 0	3370 / 2062	35054 / 27703
DISTRICT TRUTH	100	23555	3596	1020	2112	1155	113	0	595	0	3194	35642

Table 4-12

MANUAL LANDSAT COLOR COMPOSITE PER FIELD CROP CLASSIFICATION:
NODES 198, 199, 204 OF THE WHEELER RIDGE MARICOPA WATER STORAGE DISTRICT, 1974

RS CLASSIFICATION / DISTRICT GROUND TRUTH	% ACCURACY	COTTON	GRAPES	MELONS	TOMATOES	SUGARBEETS	WHEAT	FALLOW	ORANGES	NATURAL VEGETATION	OTHER	TOTAL
COTTON	83	92	1	7	7		1	2			1	111
GRAPES	0							1				1
MELONS	0	1	1					5			2	9
TOMATOES	0							10			1	11
SUGARBEETS	25		1			2					5	8
WHEAT	17		1				1				7	9
FALLOW	100							6				6
ORANGES	[illegible]										1	1
NATURAL VEGETATION	100									5		5
OTHER	74	1						3			14	19
TOTAL	67	94	4	7	7	2	2	27	0	5	31	120 / 179

Table 4-13

MANUAL LANDSAT COLOR COMPOSITE ACREAGE WEIGHTED CROP CLASSIFICATION AND WATER DEMAND PREDICTION:
NODES 198, 199, 204 OF THE WHEELER RIDGE-MARICOPA WATER STORAGE DISTRICT, 1974

RS CLASSIFICATION (AC) / DISTRICT GROUND TRUTH (AC)	% ACCURACY	COTTON	GRAPES	MELONS	TOMATOES	SUGARBEETS	WHEAT	FALLOW	ORANGES	NATURAL VEGETATION	OTHER	TOTAL
COTTON	85	7430	15	640	480		80	70			80	8795
GRAPES	0							15				15
MELONS	0	160	80					360			80	680
TOMATOES	0							600			80	680
SUGARBEETS	27		80			160					360	600
WHEAT	13		110				80				440	630
FALLOW	100							600				600
ORANGES	0										45	45
NATURAL VEGETATION	100									320		320
OTHER	68	80						240			680	1000
TOTAL	70	7670	285	640	480	160	160	1885	0	320	1765	9270 / 13365
RS WATER DEMAND PREDICTION acre feet / ABS. REL.	92 / 70	25311 / 24519	264 / 0	1920 / 0	1440 / 0	560 / 560	176 / 88	0 / 0	0 / 0	0 / 0	5965 / 2204	36257 / [illegible]
DISTRICT TRUTH	100	29024	47	2940	2040	2160	693	0	135	0	3783	59459

Table 4-14

MANUAL LANDSAT COLOR COMPOSITE ACREAGE WEIGHTED CROP CLASSIFICATION AND WATER DEMAND PREDICTION
NODES 197, 198, 199, 204, 205, 206 OF THE WHEELER RIDGE-MARICOPA WATER STORAGE DISTRICT, 1974

R.S. CLASSIFICATION (AC.) / DISTRICT GROUND TRUTH (AC.)	% ACCURACY	COTTON	GRAPES	MELONS	TOMATOES	SUGARBEETS	WHEAT	FALLOW	ORANGES	NATURAL VEGETATION	OTHER	TOTAL
COTTON	88	14060	185	740	600	40	205	115			80	16025
GRAPES	80	140	930					65			40	1175
MELONS	0	340	160					360			160	1020
TOMATOES	0	125	292			185		690			92	1384
SUGARBEETS	28	115	80			265		80			390	930
WHEAT	22		110				170				505	785
FALLOW	75	120						820			160	1100
ORANGES	65		40						155		45	240
NATURAL VEGETATION	100									600		600
OTHER	66	135					160	360			1290	1945
TOTAL	73	15035	1797	740	600	490	535	2490	155	600	2762	18290 / 25204
R.S. WATER DEMAND PREDICTION (acre feet) ABS \ REL	94 / 73	45610 / 46398	5571 / 2883	2220 / 0	1600 / 0	1715 / 928	586 / 187	0 / 0	465 / 465	0 / 0	3336 / 4360	71309 / 55221
DISTRICT TRUTH	100	52883	3645	3060	4152	3255	664	0	720	0	6574	75151

from which training data can be selected. Once selected, the next task is to identify the coordinate location of the fields in order to train the digital classification algorithm. This is accomplished by digitizing the coordinates of rectangular areas within each of the training fields on either an alphanumeric line printer or film-writer output of a single rectified LANDSAT band. In this particular study, a "tickmark" mask superimposed around the border allowed calibration between the digital and photographic coordinates. Once digitization was completed the training field coordinates were graphically scribed onto a channel of the LANDSAT data set to judge the digitization accuracy (see Figure 4-17). Since a per field classifier was implemented using LARSYS software, all 408 test field boundaries in the six node area were also coordinate digitized.

Channel Selection: Conventional digital classification algorithms are usually based upon a maximum likelihood discriminant function. It has been previously discussed and is intuitively obvious that multidate analyses should allow better crop identification performance than single date analysis. Contrary to intuition, however, continual addition of dates or channels does not always improve crop identification performance. Also, substantial increases in computation costs accrue with each additional channel. It has been observed in many instances that four or five channels of LANDSAT MSS data usually provide maximum classification accruacies, with additional channels sometimes even resulting in degraded performance.[1] The basis for this phenomenon, which has been aptly termed the "curse of dimensions," lies within the assumptions made by most classification algorithms. In addition to normal distributions, each class training set is assumed to be randomly representative of the entire class distribution. Maintaining constant confidence levels in class assignments, as additional channels are added, requires increased sampling. It also follows that increasing the number of dates involved increases the likelihood of training set degradation or capture by non-representative or irrelevant samples. In many regions it is simply not feasible to acquire an adequately representative sample of training data in accordance with the highly dimensional nature of temporal imagery that satellite systems such as LANDSAT can provide. In accordance with this, there usually exists an optimal subset of available channels for which classification performance is maximized.

A statistical measure termed "divergence" is commonly used to select the best subset of channels by which a classification is to be performed. All class pairwise combinations and channel combinations are individually evaluated. As in the maximum likelihood classification

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[1] Steiner, Dieter, "Time Dimension for Crop Surveys from Space," Photogrammetric Engineering, February 1970, Vol. 3, pp. 187-194.

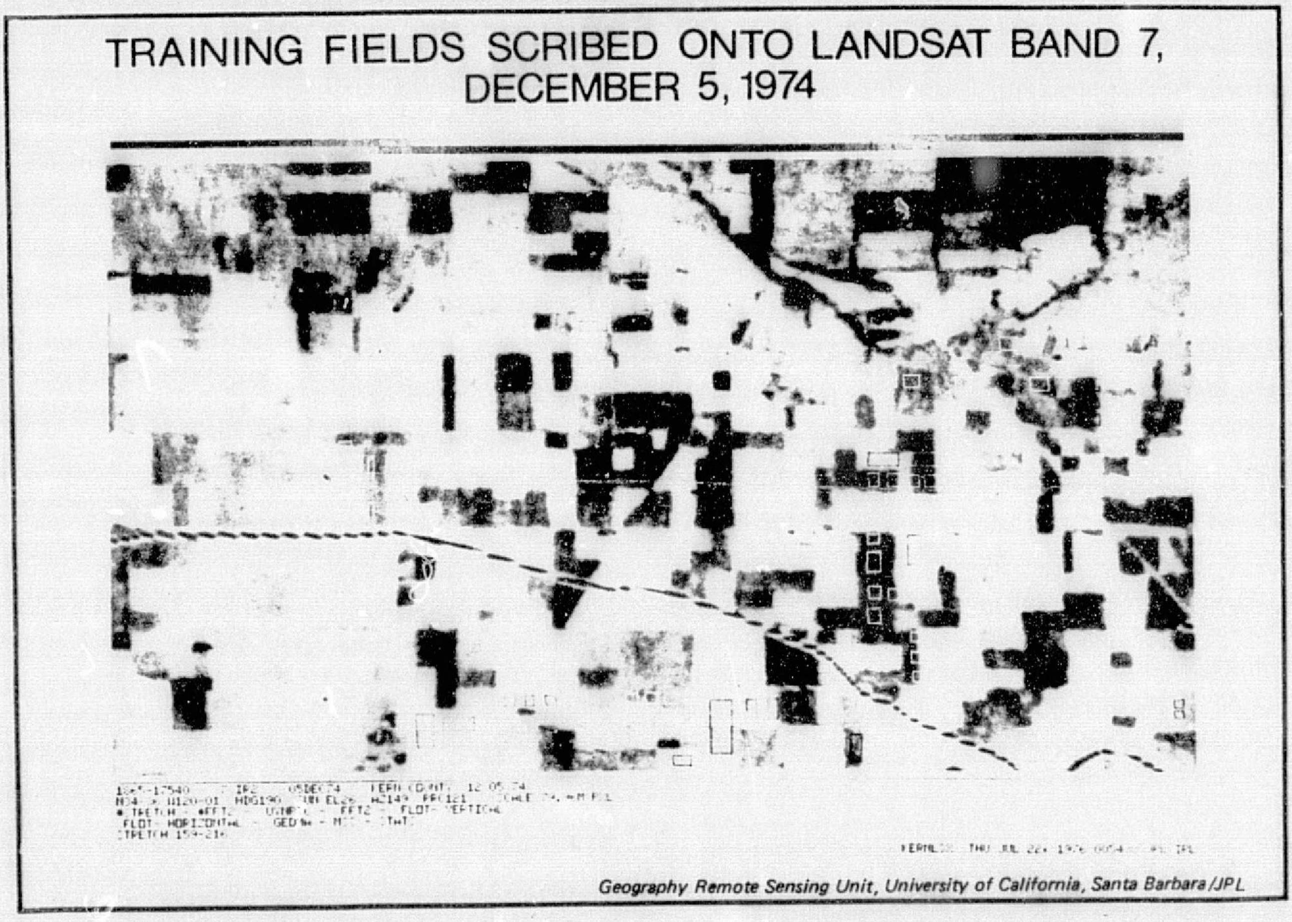

Figure 4-17. Training fields scribed onto a single band of LANDSAT imagery to assess location accuracy.

algorithm, an assumption is made that all class training data is normally distributed and representative of the test data. Each class pairwise combination in the divergence calculations may be weighted according to class *a priori* probabilities.

Classification: All test fields of LANDSAT data are classified using the LARSYS per field classification algorithm. This algorithm is based upon an equally weighted maximum likelihood desision rule. A simple maximum likelihood decision rule is one which treats each pixel independently and assigns a pixel having pattern measurements or features *d* to that category *c* whose samples are most probable to have given rise to pattern or feature vector *d*, that is, such that the conditional probability of *d* given *c*, *P(C/D)*, is highest.[1] Normal or "gaussian" distributions are assumed to exist.

LANDSAT Digital Crop Identification and Water Demand Prediction Results: With LANDSAT digital data sets preprocessed into geometric congruency, training and test field coordinates identified, and channel selection performed via divergence, a LARSYS per field classifier is applied to the test regions. Figure 4-18 depicts the classifications derived from the LARSYS per field classifier which can be compared with the district ground truth presented in Figure 4-12. A per pixel output of the data set (11/4/76 MSS; 8/19/74 MSS 5, 7; 12/5/74 MSS 7) is shown in Figure 4-19.

The primary test area was classified 78% correctly resulting in an 80% accurate water demand prediction (Table 4-15). The digital classification of the primary test site would have achieved significantly higher accuracies if the grape fields were excluded from the analyses. Of the 56 grape fields in the primary test region, 46 were less than 40 acres in size. Consequently, LANDSAT's 80m resolution was hard pressed to accurately classify these fields since the original CCT data was sampled at every fourth pixel. This accounts for the large misclassification of grape acreage as fallow (445) natural vegetation (470), and melons (190) in nodes 205 and 206 (compare Table 4-15 with Figures 4-12 and 4-18).

The LANDSAT CCT analysis of the secondary test area resulted in an 86% accurate acreage weighted crop identification and an 85% absolute water demand prediction. This represents an increase in absolute water demand prediction accuracy of 20% and 15% over the manual high altitude (Table 4-8) and manual LANDSAT (Table 4-13) techniques, respectively.

Table 4-17 summarizes the total primary and secondary LANDSAT

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[1] Haralick, Robert M., "Glossory and Index to Remotely Sensed Image Pattern Recognition Concepts," Pattern Recognition, 1973, Vol. 5, pp. 391-403.

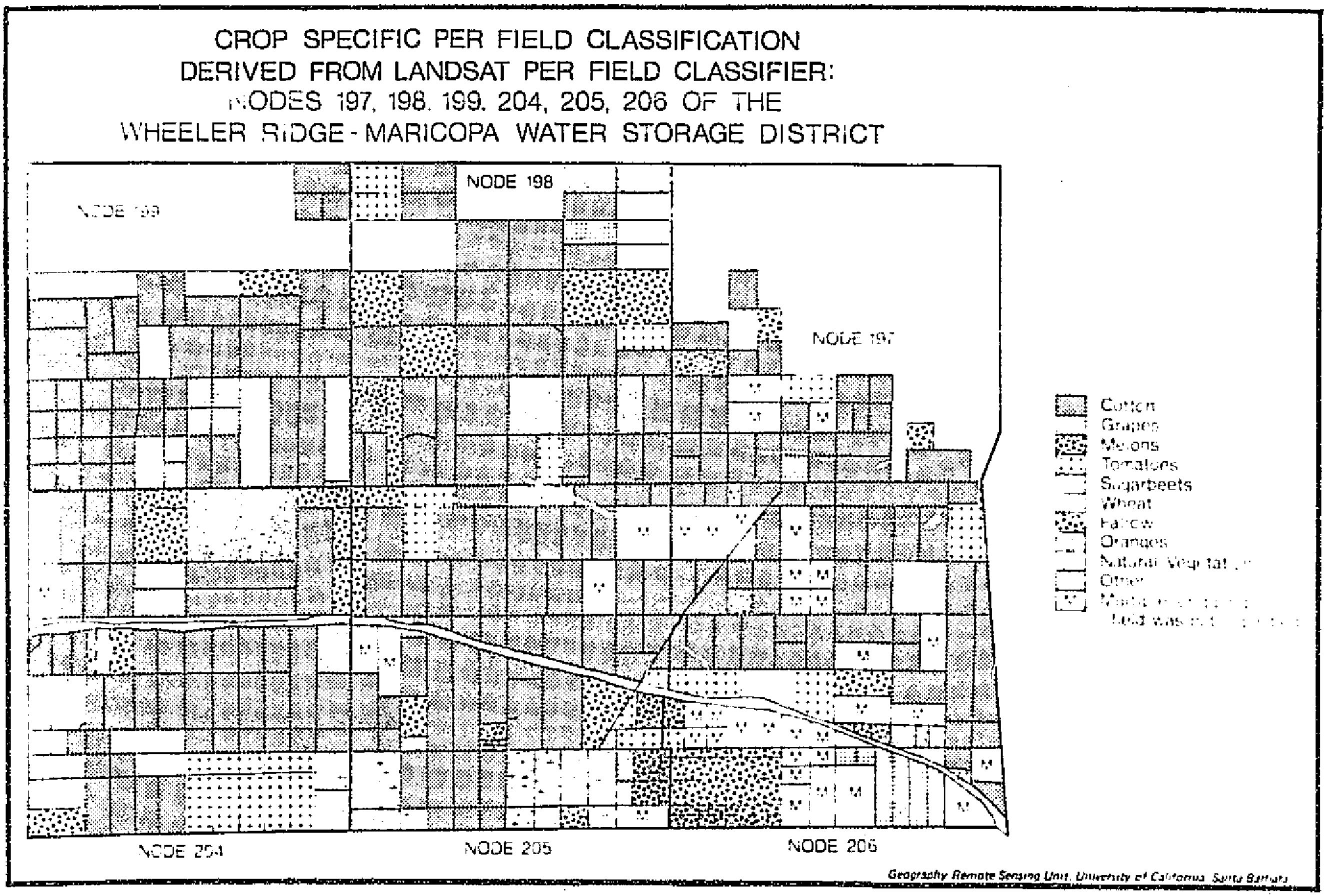

Figure 4-18. LANDSAT digital crop classification of the 1974 growing season in the Wheeler Ridge-Maricopa Water Storage District, Kern County, California.

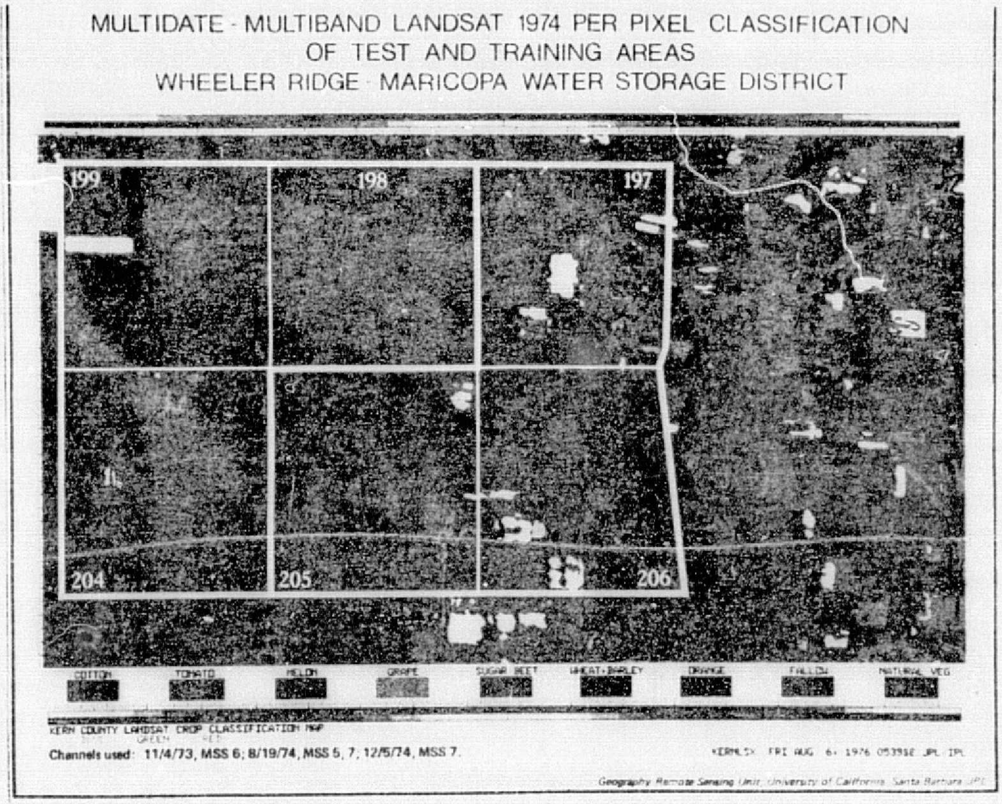

Figure 4-19 . LANDSAT per pixel classification map of the training and test (197, 198, 199, 204, 205, 206) areas in the Wheeler Ridge-Maricopa Water Storage District in Kern County, California.

Table 4-15

DIGITAL ACREAGE WEIGHTED
LANDSAT MULTIDATE–MULTIBAND CROP CLASSIFICATION AND WATER DEMAND PREDICTION
NODES 197, 205, 206 OF THE WHEELER RIDGE – MARICOPA WATER STORAGE DISTRICT 1974

R.S. CLASSIFICATION (AC) \ DISTRICT GROUND TRUTH (AC)	% ACCURACY	COTTON	GRAPES	MELONS	TOMATOES	SUGARBEETS	WHEAT	FALLOW	ORANGES	NATURAL VEGETATION	OTHER	TOTAL
COTTON	98	7020		10	180		20					7230
GRAPES	1		55	190				445		470		1160
MELONS	35	140		120	80							340
TOMATOES	48		24	75	330	90	185					704
SUGARBEETS	11	60			80	35		155				330
WHEAT	42						65	90				155
FALLOW	76	40						380	80			530
ORANGES	51			65		30			100			195
NATURAL VEGETATION	100									280		280
OTHER	90	80						12			853	945
TOTAL	78	7340	79	460	670	155	270	1082	180	750	853	9258 \ 11839
R.S. WATER DEMAND PREDICTION acre feet ABS\REL	90 \ 80	24222 \ 23166	245 \ 171	1380 \ 360	2010 \ 990	543 \ 123	297 \ 72	0 \ 0	540 \ 300	0 \ 0	2863 \ 3211	32120 \ 28426
DISTRICT TRUTH	100	23859	3596	1520	2112	1155	171	0	585	0	3194	35692

Table 4-16

DIGITAL ACREAGE WEIGHTED
LANDSAT MULTIDATE–MULTIBAND CROP CLASSIFICATION AND WATER DEMAND PREDICTION
NODES 198, 100, 204 OF THE WHEELER RIDGE – MARICOPA WATER STORAGE DISTRICT 1974

R.S. CLASSIFICATION (AC) \ DISTRICT GROUND TRUTH (AC)	% ACCURACY	COTTON	GRAPES	MELONS	TOMATOES	SUGARBEETS	WHEAT	FALLOW	ORANGES	NATURAL VEGETATION	OTHER	TOTAL
COTTON	97	8495		140	80			80				8795
GRAPES	0			15								15
MELONS	0	160			80		220	220				680
TOMATOES	88				600			80				680
SUGARBEETS	27				160	160	180	100				600
WHEAT	100						630					630
FALLOW	100							600				600
ORANGES	0										45	45
NATURAL VEGETATION	100									320		320
OTHER	70	60					60	160			700	1000
TOTAL	86	8735	0	155	920	160	1090	1240	0	320	745	11505 \ [illegible]
R.S. WATER DEMAND PREDICTION acre feet ABS\REL	92 \ 85	28926 \ 28034	0 \ 0	465 \ 0	2760 \ 1800	560 \ 560	1199 \ 693	0 \ 0	0 \ 0	0 \ 0	2518 \ 2566	36328 \ 33453
DISTRICT TRUTH	100	29024	47	2046	2040	2100	693	0	135	0	3380	33459

Table 4-17

DIGITAL ACREAGE WEIGHTED
LANDSAT MULTIDATE–MULTIBAND CROP CLASSIFICATION AND WATER DEMAND PREDICTION
NODES 197, 198, 199, 204, 205, 206 OF THE WHEELER RIDGE – MARICOPA WATER STORAGE DISTRICT, 1974

R.S. CLASSIFICATION (AC) / DISTRICT GROUND TRUTH (AC)	% ACCURACY	COTTON	GRAPES	MELONS	TOMATOES	SUGARBEETS	WHEAT	FALLOW	ORANGES	NATURAL VEGETATION	OTHER	TOTAL
COTTON	97	15515		150	260		20	80				16025
GRAPES	5		55	205				445		470		1175
MELONS	12	300		120	160		220	220				1020
TOMATOES	67		24	75	930	90	185	80				1384
SUGARBEETS	21	60			240	195	180	255				930
WHEAT	86						695	90				785
FALLOW	89	40						980	80			1100
ORANGES	42			65		30			100		45	240
NATURAL VEGETATION	100									600		600
OTHER	80	160					60	172			1555	1945
TOTAL	82	16075	79	615	1590	315	1360	2322	180	1070	1598	20743 \ 25204
R.S. WATER DEMAND PREDICTION acre feet ABS \ REL	91 \ 82	53048 \ 51200	245 \ 171	1845 \ 360	4770 \ 2790	1103 \ 683	1496 \ 765	0 \ 0	540 \ 300	0 \ 0	5401 \ 5249	68448 \ 61518
DISTRICT TRUTH	100	52833	3643	3060	4152	3255	664	0	720	0	6574	75151

Table 4-18

SUMMARY OF MANUAL AND DIGITAL CROP CLASSIFICATION AND WATER DEMAND PREDICTION
WHEELER RIDGE–MARICOPA WATER STORAGE DISTRICT

CLASSIFICATION METHOD		PRIMARY	SECONDARY	TOTAL AREA	ACREAGE WEIGHTED PRIMARY	ACREAGE WEIGHTED SECONDARY	ACREAGE WEIGHTED TOTAL AREA	PRIMARY WATER DEMAND ACCURACY	SECONDARY WATER DEMAND ACCURACY	TOTAL WATER DEMAND ACCURACY
MANUAL	HIGH ALTITUDE	72	60	66	71	63	66	73	65	70
	LANDSAT	76	67	71	76	70	73	78	70	73
DIGITAL	LANDSAT	63	86	73	78	86	82	80	85	82

Performance of 2 interpreters (1 high altitude, 1 LANDSAT) from a group of eight interpreters (4 high altitude, 4 LANDSAT). Acreage weighted accuracies and water demand predictions necessitate using a single interpreter's results

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digital performance. An 82% accurate crop identification yielded an 82% absolute water demand prediction. The 91% accurate relative water demand prediction is 3% lower than the manual LANDSAT (Table 4-14) and 7% lower than the manual high altitude (Table 4-9). This suggests that although the relative water demand accuracies are high, it would not be advantageous to conduct a water demand survey hoping that if misclassifications occur they will correspond to similar water demanding crops. As shown here, there may be a decline in this relative water demand accuracy which could be more pronounced in other environments. The ideal is to base a water demand prediction on crop inventories which the user feels are absolutely accurate.

Table 4-18 is provided to summarize the manual and digital crop classifications and water demand prediction results presented thus far. Note that there is a hierarchy with the LANDSAT digital approach being the most effective and manual high altitude the least. Of course, the user must carefully evaluate the tradeoff between technique costs and possible returns. Analyses of the equipment and implementation costs for the specific techniques in Appendix I enable the user to make a decision.

4.46 Digital Crop Identification of Multidate LANDSAT Transparencies Using a Point Densitometer and Discriminant Analysis Classification Algorithm (C).

The previous LANDSAT digital crop identification procedure requires substantial hardware and programming expertise. Also, the cost of computer compatible tapes (CCTs) at $200 per date is a serious constraint to many users. Consequently, considerable research has gone into the development of procedures which allow agencies with modest equipment expense and a "packaged" discriminant analysis program available at many computer facilities to conduct repeatable, computer assisted crop identification. A 1973 crop identification and water demand prediction for node 199 in the Wheeler Ridge-Maricopa Water District will be demonstrated using this technique.

LANDSAT Image Inventory, Assessment, Acquisition, and Formatting: These procedures are adequately defined in the manual LANDSAT crop identification procedure. The only difference here is that instead of color composites, each individual channel available throughout the growing season is ordered in a positive transparency format. For example, Table 4-19 lists the available 1973 MSS imagery of node 199 purchased. The 1:1,000,000 scale transparencies are already in a suitable format as this technique does not require geometric rectification if reasonable (5 square miles) test regions are under investigation.

Ground Truth, Field Boundary Overlay and Crop Phenology Information: Each of these previously discussed components is necessary, however, the field boundary overlay (Figure 4-14) is of critical importance in this

Table 4-19

Inventory of 1973 LANDSAT Imagery for Node 199
in the Wheeler Ridge-Maricopa Water District

Date		Bands Available
January	2	4 5 6 7
January	20	6 7
February	7	clouds
February	25	4 5*6*7*
March	14	4 5 6 7
April	2	4*5*6*7*
April	20	4*5*6*7*
May	7	4*5*6*7*
May	26	4 5 6 7
June	12	4*5*6*7*
June	30	4 5 6 7
July	18	4*5*6*7*
August	6	clouds
August	23	4*5*6*7*
Sept	11	4 5 6 7
Sept	29	clouds
October	17	4*5*6*7*
November	4	4 5 6 7
November	22	clouds
December	9	clouds
December	28	clouds

* bands purchased

procedure. The task of identifying individual fields on 1:1,000,000 LANDSAT transparencies is accomplished by producing field boundary maps for each node or group of nodes and then photographically reducing these outline maps to the exact scale of the LANDSAT imagery (see rightmost image on Figure 4-22). The inclusion of permanent features on this field boundary map such as canals, highways, etc., makes alignment of the reduced overlay upon the transparencies a relatively simple task. The most important requirement for this approach is that precision photographic facilities be available to insure accurately scaled field boundary reductions.

Training and Test Field Selection and Data Extraction: As each field in a region is assigned a specific number, the selection of training and test fields becomes a straightforward matter when used in conjunction with a limited amount of field verified data. The field boundary overlay provides its most important function as a method for multiple image correlation with data extracted on a per-field basis from successive images. This data extraction may be accomplished in a variety of ways including the use of an inexpensive optical or video point densitometer (see Figures 4-20 and 4-21 respectively). An added advantage of the video densitometer is its potential for computer controlled point data extraction if digitization hardware and software can be appended. Nevertheless, the simple optical densitometer can be used to manually extract point density measurements for training and test fields for all bands desired.

Important elements of this capability are apparent. Instead of being restricted to just a few dates in the growing season due to CCT costs, the user now has the option of analyzing all potential channels and then selecting an optimum subset for crop identification.

Crop Classification and Water Demand Prediction: With training and test data extracted on a per field basis and an intuitive evaluation made concerning optimum channels to be used in the classification, the dataset is ready to be interrogated. There are numerous discriminant analysis "packaged" programs available. Output presented here documents the Statistical Package for the Social Sciences (1976) whereas previous research used UCLA's Biomedical Statistical Package BMDP-Biomedical Computer Programs (1975). The variables used in these analyses are the density values for the LANDSAT bands selected. The groups are the croptypes under consideration. By training the computer on known fields a contingency table showing training performance is produced. Table 4-20 documents such results for the 24 training fields in the node 199 example. Except for discriminating melons, the training data appears to be adequate. With the classifier trained on these 24 fields it can now be applied to the 52 test fields which are not given a class code (i.e. croptype) when input to the classifier. The discriminant analysis algorithm assigns each "unknown" case to that group of which it has the highest probability of being a member. When using these packages the user must manually evaluate classified

Figure 4-20. Macbeth point densitometer. (Macbeth Corporation, Newburgh, New York.)

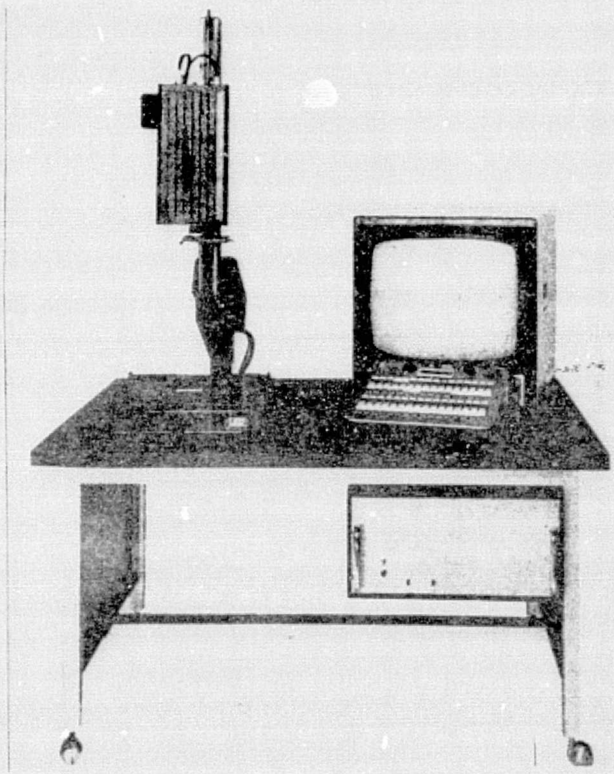

Figure 4-21. Spatial Data video densitometer. (Spatial Data Systems, Inc., Goleta, California.)

Table 4-20

DIGITAL LANDSAT TRAINING FIELD CROP CLASSIFICATION:
NODE 199 OF THE WHEELER RIDGE-MARICOPA WATER STORAGE DISTRICT, 1973

R.S. CLASSIFICATION / DISTRICT GROUND TRUTH	% ACCURACY	BARLEY	COTTON	MELONS	SUGARBEETS	SAFFLOWER	TOTAL
BARLEY	80	4	1				5
COTTON	100		5				5
MELONS	40	1	1	2		1	5
SUGARBEETS	60				3	2	5
SAFFLOWER	100					4	4
TOTAL	75	5	7	2	3	7	18 / 24

Table 4-21

DIGITAL LANDSAT TEST FIELD CROP CLASSIFICATION:
NODE 199 OF THE WHEELER RIDGE-MARICOPA WATER STORAGE DISTRICT, 1973

R.S. CLASSIFICATION / DISTRICT GROUND TRUTH	% ACCURACY	BARLEY	COTTON	MELONS	SUGARBEETS	SAFFLOWER	TOTAL
BARLEY	60	3		1		1	5
COTTON	100		35				35
MELONS	0				3	2	5
SUGARBEETS	67				2	1	3
SAFFLOWER	100					4	4
TOTAL	85	3	35	1	5	8	44 / 52

Table 4-22

DIGITAL LANDSAT TEST FIELD ACREAGE WEIGHTED CROP CLASSIFICATION
AND WATER DEMAND PREDICTION:
NODE 199 OF THE WHEELER RIDGE-MARICOPA WATER STORAGE DISTRICT, 1973

R.S. CLASSIFICATION (AC.) / DISTRICT GROUND TRUTH (AC.)	% ACCURACY	BARLEY	COTTON	MELONS	SUGARBEETS	SAFFLOWER	TOTAL
BARLEY	40	160		160		80	400
COTTON	100		2520				2520
MELONS	0				160	160	320
SUGARBEETS	75				240	80	320
SAFFLOWER	100					160	160
TOTAL	83	160	2520	160	400	480	3080 / 3720
R.S. WATER DEMAND PREDICTION (acre-feet) ABS. \ REL.	95 / 87	176 / 176	7339 / 7838	458 / 0	1140 / 684	1593 / 533	11260 / 9231
DISTRICT TRUTH	100	440	7888	915	912	533	10588

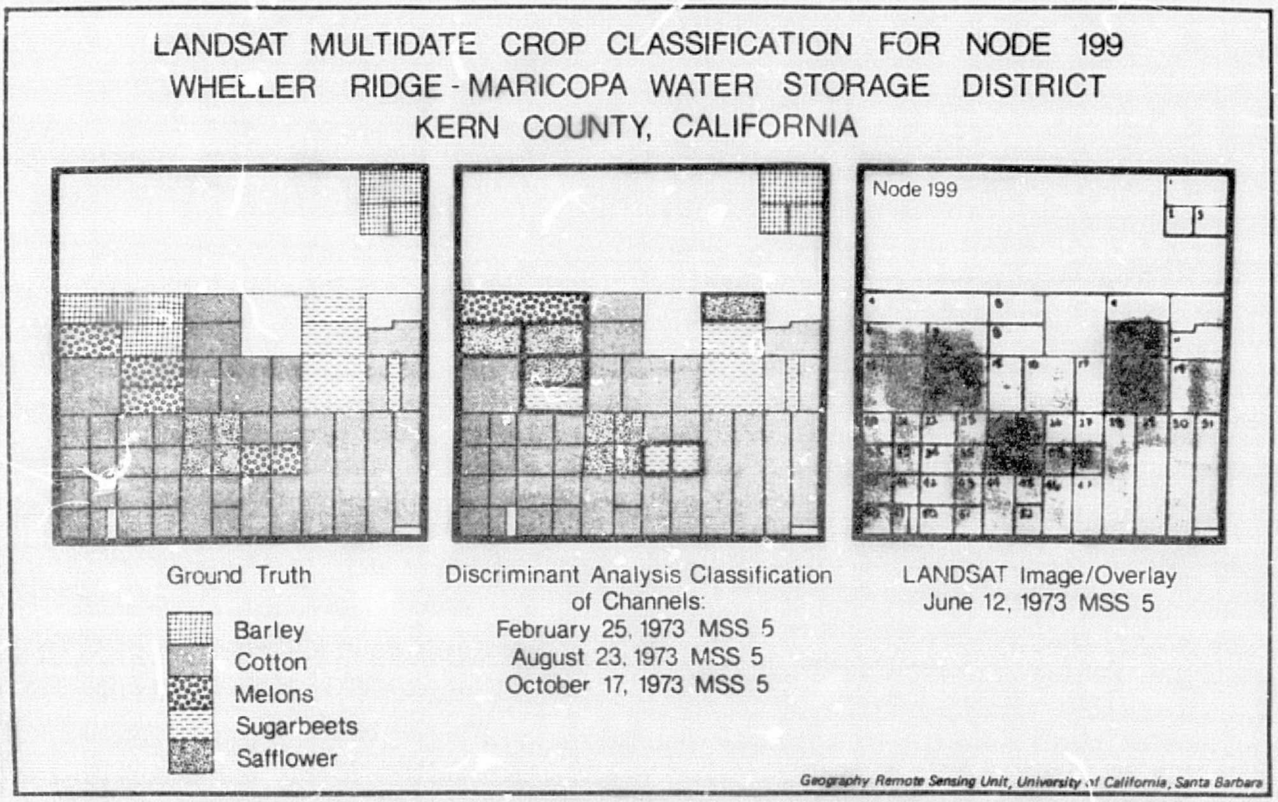

Figure 4-22. A discriminant analysis classification map of the three most optimum channels (as specified by divergence statistics) compared with the ground truth map. Note the LANDSAT image/overlay which facilitates registration and data extraction of multidate images on a per-field basis. Crop identification and water demand accuracies associated with this inventory are given in Table 4-22.

test data in order to derive the test region contingency table illustrated in Table 4-21. The results of the Node 199 classification are presented in map format in Figure 4-22. With a small amount of programming the per field statistics can be manipulated to yield both the acreage weighted crop identification and water demand prediction desired (Table 4-22). In this instance, the user must provide per field acreages and local water application rate statistics.

The "packaged" discriminant analysis programs normally plot the location of the cases according to their scores on the first two canonical variables. This is valuable because one can visually identify those fields which are incorrectly classified and analyze them in relation to their cluster location (Figure 4-23). In the Node 199 example it is apparent why the cotton classification was so high. Most all of the cotton training and test data exhibit signatures which cluster in a region separate from all other classes. Conversely, by re-evaluating the training class statistics in Table 4-20 in conjunction with Figure 4-22 we realize why melons are misclassified. Most melon training fields are located in other croptype regions. An iteration of the entire classification procedure with new melon training data might improve the test region melon classification.

While this technique is tailored to users with little equipment and software, it has a great potential for maximizing CCT digital classification techniques previously discussed. Agencies capable of doing CCT interrogation often have image digitization capabilities. Consequently, computer controlled digitization and per field data extraction could take place for training fields in each channel throughout the growing season. This data could be input to the LARSYS statistical separability analysis termed "divergence." Divergence rank orders subsets of images (i.e. all combinations of channels as specified such as two, three, or four at a time) in terms of their class identification capability. Consequently, by investing a relatively small amount of dollars in transparencies and data extraction, the agency could make improved CCT purchases by knowing the optimum dates beforehand.

4.5 SUMMARY

The agricultural water demand prediction procedures were developed for a representative semi-arid region in central California. They may be applied to other water demanding regions if careful attention is given to the following procedural steps:

* Empirically identify the regionally important nature of the water demand prediction variables, i.e. which parameters account for the most variance in the prediction procedure.

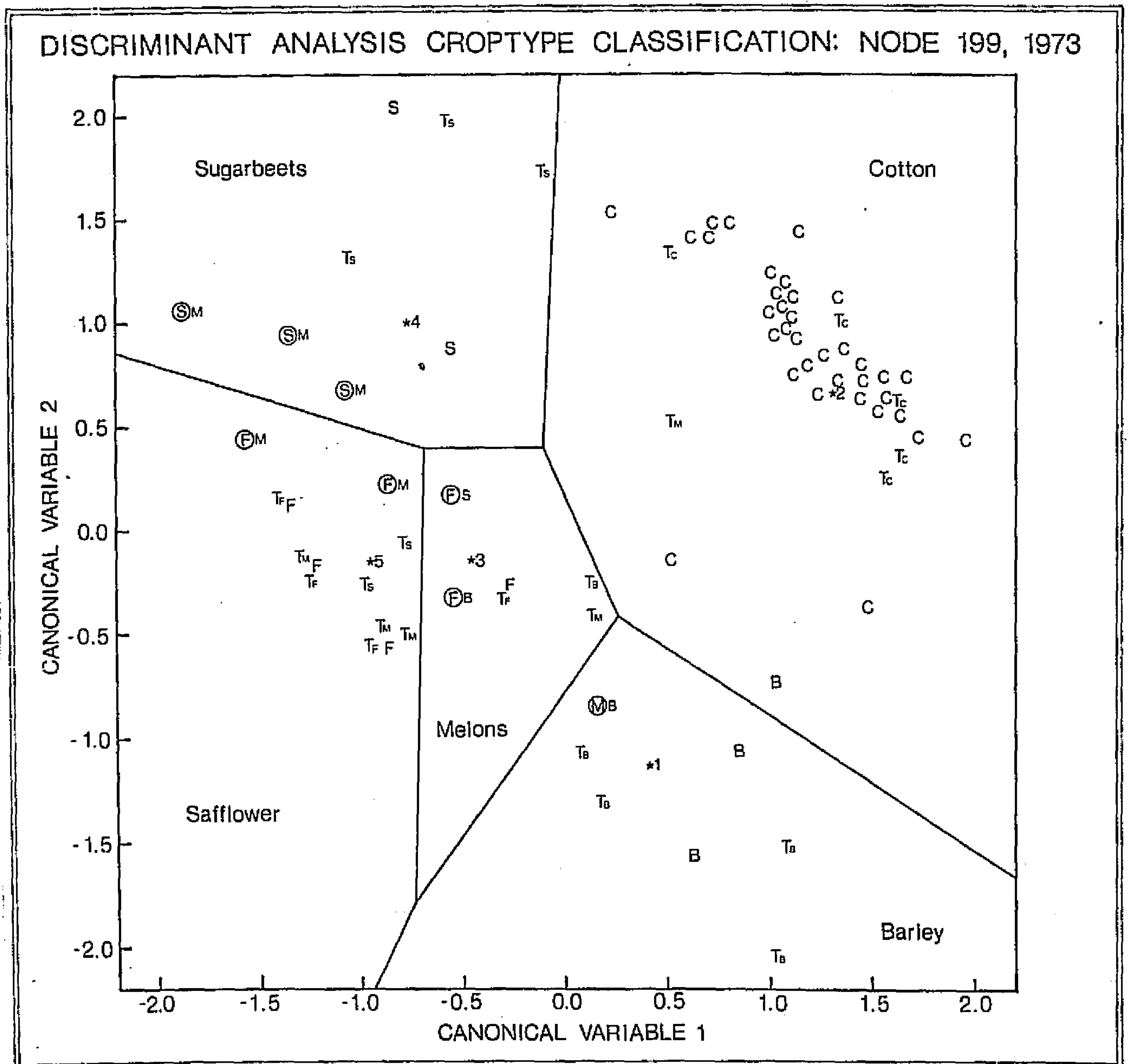

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Figure 4-23. LANDSAT based discriminant analysis crop classification of Node 199 (Wheeler Ridge-Maricopa Water Storage District), 1973 growing season. Plotted are the first two canonical variables derived from 2/25/73-MSS 5, 8/23/73-MSS 5, and 10/17/73-MSS 5 imagery. Decision boundaries separate the five fairly distinct clusters, each representing a different croptype. Training fields from surrounding nodes are identified by letters T = barley, T = cotton, T = melons, T = sugarbeets, T = safflower; class means are shown as *1, *2, *3, *4, and *5 respectively. Test data (B, C, M, S, F) represent individual fields of Node 199. Fields misclassified are circled and correct classification, according to Water District crop map, are subcripted.

* Evaluate information sources and identify those parameters which due to temporal or accuracy constraints should be inventoried using remote sensing techniques. Based on previous research, it is assumed that the agricultural landcover will be a major model driver.

* Select one of the inventory techniques by evaluating the level of information detail required and the agency's hardware, software, and collateral information resources.

* Conduct the agricultural landcover inventory.

* Develop spatially accurate water demand predictions by interrogating the landcover dataset in conjunction with average irrigation rates.

The water demand estimates may then be used to make short and long-term water resource management decisions regarding groundwater recharge, taxation schedules, and/or intra-regional water transfer.

4.6 FUTURE WORK

The proposed research for the period beginning May 1, 1977 will be to perform a total resource complex inventory of the valley portion of Kern County, California. As the Geography Remote Sensing Unit has continually interfaced with public user agencies to identify information requirements and, in addition, has acquired a substantial amount of collateral information on this region in the past, we feel that the only viable method of modeling the total resource complex is to develop an analytical geobase information system. The most significant driver of this information system will be the use of digital LANDSAT thematic products which will monitor dynamic topics. Such data will be merged with other collateral information such as soils, groundwater, census, etc., to yield higher order integrative data which is spatially accurate and useful for Kern County decision makers. By April, 1978, GRSU will document the procedural manner in which other regions can initiate and successfully operate a total resource complex information system such as that developed for the Kern County study area.

APPENDIX I

MANUAL (A) AND DIGITAL CCT (B) CROP IDENTIFICATION

TECHNIQUES COST AND EQUIPMENT ANALYSIS

This section summarizes the cost and equipment requirement for conducting the manual and digital CCT crop identifications for the entire six node study area of the Wheeler Ridge-Maricopa Water District. This six node agricultural region has 408 fields totaling approximately 27,700 acres.

Manual:

The statistics presented in Table 4-23 represent:

* The costs of the physical meterials and labor required to produce the image/crop calendar keys.

* The interpretation cost for classifying both the primary and secondary test areas.

Results indicate that for operational considerations there is no appreciable difference in cost between the highflight and LANDSAT approaches i.e., only $42 separates them. Since there was no significant difference in the classification accuracy of the manual high altitude and LANDSAT interpretations, we consider it interesting that the costs are also very comparable. This suggests that resource managers may take maximum advantage of either medium i.e., high altitude photography or LANDSAT imagery, when available for their particular study area and that comparable accuracies and costs could result.

Also of importance is the very minimal amount of capital equipment required to conduct manual crop identifications. Table 4-24 identifies the only major item as being a photographic laboratory capable of enlargement/reduction and modest color production. However, an agency could use standard commercial processing if necessary.

Digital:

The statistics presented in Table 4-25 represent the costs of:

* Computer compatible tapes (CCT)

* Geometric rectification and registration

* Channel selection divergence

* Classification, and

* An image analyst (programmer).

Compared to the mean cost of the manual techniques, the digital LANDSAT approach was approximately 3 times more expensive. A major factor associated with the processing of the digital LANDSAT data is the cost of tape acquisition from the EROS Data Center, Sioux Falls, South Dakota. This cost alone is nearly twice the amount required to conduct the entire analysis using either of the manual techniques.

Digital image processing required to accomplish the crop identification goals set out in our analysis necessitates access to sophisticated computer hardware and software such as the types seen in Table This table shows the characteristics of a minimum and desired computer configuration for digital crop identification and those facilities used in our analysis. The minimum computer capability required for a low-cost data system is shown in the third column. If a computer of the minimum capability is used, the data processing time will be longer. It may be necessary to process the imagery through the computer two or more times to classify the data. Addition of computer memory is recommended where high throughput rates are required. The fourth column shows an adequate computer configuration for most potential users of remote sensing, even for state-sized survey areas.

Table 4-23. Cost of Manual Crop Identification for the Primary and Secondary Test Areas of the Wheeler Ridge-Maricopa Water District Kern County, California*

High Altitude:

Original positive transparencies from EROS	4 @ $12	=$ 48.00
Cibachrome paper prints	8 @ $ 7	=$ 56.00
Image and Crop Calendar key creation	60 hrs @ $ 5	=$300.00
Interpretation time	8 hrs @ $ 5	=$ 40.00
		$444.00

LANDSAT:

Original positive transparencies from EROS	16 @ $ 5	=$ 80.00
Color Combiner 8X10" Ektacolor film	4 @ $ 3	=$ 12.00
Develop 8X10" negatives	4 @ $ 3	=$ 12.00
Paper prints	8 @ $ 6	=$ 48.00
Image and Crop Calendar key creation	60 hrs @ $ 5	=$300.00
Interpretation time	8 hrs @ $ 5	=$ 40.00
		$482.00

* The costs reported include the cost of image acquisition from readily available sources, but does not include the cost of aircraft or satellite mobilization.

Table 4-24. Equipment Required for Manual and Digital Crop Identification

Manual:

- Photographic laboratory for making field boundary overlays (i.e. enlargement & reduction of images)

Digital:

CATEGORY	FACILITIES USED IN OUR ANALYSIS	MINIMUM	DESIRED
Central Processor Unit with Operators Console	yes	yes	yes
Memory	yes	16K, 16 bit words	64K,16 bit words
Tape Drives (CCT)	yes	Two 7 or 9 track	Two 9 track, 3.05 MPS (120 IPS), 315 Byt/cm (800BPI)
Disc (Rotating Memory Device)	yes	12M, 16 bit words	46M, 16 bit words
Line Printer	yes	yes	yes
Electrostatic Printer	no	no	yes
Card Reader	yes	yes	yes
Floating Point Hardware	yes	no	yes
Micro Programmable Writable Control Storage	no	no	yes
Operating System	yes	no	yes
FORTRAN Compiler	yes	yes	yes
Optical Mechanical Scanner	yes	no	yes
APPROXIMATE COST		\$75-80K	\$200-250K

Table 4-25. Cost of Digital Crop Identification for the Primary and Secondary Test Areas of the Wheeler Ridge-Maricopa Water District Kern County, California

LANDSAT:

Computer Compatible Tapes from ERTS	4@ $200	=$	800.00
Geometric Rectification and Registration 16 Channels x 5 min cpu @ $100/hr (JPL)		=	133.00
16 channel divergence: combinations of 4 channels 58.3 min cpu (UCSB) + 2000 Disk I/O		=	71.00
4 channel classification 76.3 min cpu (UCSB) + 6000 Disk Tape I/O		=	203.00
Image Analyst (programmer) 30 hrs @ $10./hr.		=	300.00
			$1507.00

CHAPTER 5

USE OF REMOTE SENSING TO INVESTIGATE WATER AND OTHER RESOURCE ALLOCATIONS IN SOUTHERN CALIFORNIA

Co-Investigator: Leonard W. Bowden, Riverside Campus
Contributors: Claude W. Johnson, David A. Nichols, James R. Huning, and Richard Bartko

Chapter 5

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Chapter 5.

USE OF REMOTE SENSING TO INVESTIGATE WATER AND OTHER RESOURCE ALLOCATIONS IN SOUTHERN CALIFORNIA

Co-Investigator: Leonard W. Bowden, Riverside Campus
Contributors: Claude W. Johnson, David A. Nichols, James Huning, and Richard Bartko

5.1 Summary

With the completion of the Land Use Mapping phase of the Water Demand Study of the Upper Santa Ana River Drainage Basin, the Riverside Campus assumed the task of producing a Procedural Manual for Land Use Mapping. The manual was to be written for the novice who is given the task by some public or private agency or industry to produce a land use display or map of given resources in a given area. A step by step draft procedure has been outlined and appears as section 5.2 below. At this reporting date the figures have been omitted, but will be included with the final draft, which will appear as a separate publication. It would emphasize the use of remote sensing techniques.

Because of our experience and generation of new techniques developed from the Water Demand Studies we were able to develop the Procedural Manual for Land Use Mapping. Initial reaction has been that more detail is required for several of the steps that have been outlined. One specific area of expansion that has been recommended deals with automated processing. We have shown neither the availability of computer mapping programs, nor how a user might implement these automated procedures. We have, therefore, proposed that as part of our concluding studies on the project, we include complete documentation and program clean-up for our automated land use mapping procedures. As a result, any user would be able to acquire and utilize these programs without any instructions other than the manual.

One area of the Water Demand Study that has not been investigated is a cost effective method for determining and monitoring irrigated (and non-irrigated) land within a region. The cost effectiveness restriction strongly suggests the use of LANDSAT imagery to provide the basic data for the investigation. Our current study deals with the potential use of LANDSAT temporal data to identify changes from a known base of irrigated fields in the Perris Valley region of the Upper Santa Ana River Drainage Basin. The possibilities of using image processing techniques in conjunction with the study are presently being explored.

Another study that initiated from our water demand studies has been the investigation of inter-census population estimates. The ability to accurately estimate the population, and more specifically, the actual location (as opposed to a census area) is of concern to both water resources agencies and regional planners. Population estimation studies are continuing under our current research and, if successful, will provide a technique that can be published in procedural manual form.

An ancillary investigation conducted during our water demand studies has been an attempt to establish a regional trend of permanent agricultural crops such as citrus. Partly as a result of this study, numerous citrus associations and the governing state agency have recently inquired as to the feasibility of using remote sensing techniques to assist them in their regulatory processes. Each year the Orange Administrative Committee must establish prorated quota for the flow of oranges to market. Errors in estimates of the total orange crop for the forthcoming season result in considerable monetary losses to growers, packers and processors. The governing committee representatives have indicated that they will consider providing matching funds for a feasibility research study in the above context. However, it is probable that with the termination next year of our NASA grant in its present form, all or most of the financial support required by our group for this study would need to come from other sources.

5.2 Current Study: Techniques for Mapping Land Use From Remotely Sensed Imagery - A Procedural Manual.

5.2.0 Introduction

The production of a land use map involves carrying out a series of tasks that result in an end product of pre-defined quality. The tasks may vary according to the desired quality of the product. Most land use mapping efforts have general tasks in common. These include planning, data acquisition and mapping, and data compilation. Because the general tasks normally follow one another chronologically, they may be referred to as 'phases'.

Before any land use or thematic type mapping is initiated, a planning phase should be carried out in which objectives are defined and quality control parameters are established. The phase must include consideration of how, where, when, and what type of information is to be acquired.

The second or production phase includes data acquisition and mapping. Information is transferred from the actual site (by field survey), or from remotely sensed image data to a draft map. Normally this involves categorization of the data, scale change and positional control relative to a planimetric base map.

Completion of the production or information transfer phase results in the production of a planimetrically correct draft land use map. However, two major tasks remain in order for the work to be useful to the planner. Firstly, the map must be suitably prepared for presentation and its readability enhanced. Secondly, the map information must be compiled so as to answer the question of 'how much?' as well as 'what?'. Area measurements and summaries are therefore a requisite part of any major land use mapping effort. This is termed the data compilation and presentation mapping phase.

5.2.1. Planning Phase

5.2.1.1 STEP 1 Define Goals and Objectives

a. Establish the Purpose of the Land Use Map

Despite the logical progression of the tasks necessary to map land use one must not assume at the outset that decisions relating to later tasks can be ignored. For example, it would be illogical to begin data acquisition prior

to establishment of a classification system. Also, it would be fruitless to establish a classification system without a thorough understanding of the eventual use of the map information. The ultimate use of the map dictates both cost and procedural options. Accuracy required for planning and management decisions should establish the criteria for the type of data to be collected and the resolution of those data.

b. Establish Temporal Baseline

The prime reason for the recurring need to map land use is its dynamic nature. This process of continual change always results in planners using dated information (often as much as 10 years old). A primary goal is to acquire the most up-to-date information possible in order to minimize obsolescence and maximize utility. Basically, there are two methods for acquiring land use data, each of which has ramifications with respect to establishing a temporal base.

Land use data may be obtained by means of ground survey or aerial survey. For a large land use mapping project the time required to complete a survey may be months or even years. The time lapse can lead to a situation where one portion of a study area is not temporally compatible with another portion. Aerial surveys provide data at essentially a point-in-time, resulting in temporal consistency throughout the study area.

Assuming that an aerial survey is to be used for data collection, there are still several problems in establishing the time base. These considerations relate primarily to the type of platform. If the user is able to contract privately for this service the only limitations are atmospheric clarity and suitability for flying at the desired time. However, if pre-existing imagery (usually provided by a governmental agency such as NASA) is to be used, the user must be prepared to accept the date of available coverage. The most continuous coverage is provided by Landsat imagery: at least every 18 days, not all of which may be usable. Much work remains to be done before Landsat data are useful for some urban or large-scale land use mapping applications. High altitude aircraft imagery does not provide synoptic coverage, but large areas have been imaged and may provide the needed coverage. The U.S. Geological Survey EROS Data Center provides a computer search of available governmental coverage from a variety of sensors. This search may be performed by specifying latitude and longitude coordinates for either a point or rectangle (USGS, 1976).

5.2.1.2 STEP 2 Establish Classification System

Land use has a variety of real-world expressions. Theoretically, it would be useful to attempt to identify each of these expressions unambiguously. However, such effort would require gathering and handling an inordinate and superfluous amount of data. For convenience, land use expressions are categorized and classified.

One does not classify land use to any degree of specificity greater than that required for operational applications. However, one does not want to be so general as to lose information that is essential for operation and planning purposes. The end purpose of the land use information must dictate the classification system. Because most land use classification systems are hierarchical in nature, the specificity or refinement of the system is usually indicated by user needs.

Four levels of land use classification types are generally recognized. In agriculture, a fifth level has been developed to specify certain types of food crops. An example of the hierarchical structure to four levels is provided in Table 1. Tables 5.2.2,3,& 4 contain three classification systems along with different philosophies underlying their organization.

Table 5.2.1

Excerpt from land use classification system showing hierarchical structure (C.P.O., 1968)

First level.....	5000	Trade
Second level........	5100	Wholesale trade
Third level............	5130	Dry Goods and Apparel
	5140	Groceries and Related Products
Fourth level................	5141	Groceries (general line)
	5142	Dairy Products
	5143	Poultry and Poultry Products

Resource managers who must work with both urban and rural regions, such as water resources or forest managers, prefer a dichotomous classification system (urban/rural) with hierarchical breakdowns under those two headings. Interpreters extracting general land use data from high altitude aircraft and satellite imagery often create a system that fits what can be observed from the image. This latter approach, if followed rigorously, has the tendency to confuse the final user of the map. Therefore, either the interpreters or the users must modify their mode of operation.

The primary concern, in constructing a land use classification system to be used with an image data base, is to provide at least some level of classification for all necessarily detectable land uses. Land use types that are to be differentiated, but are non-detectable from imagery, must be identified from some other data source. Fortunately, data from multiple sources are easily mixed so that the best land use information can be used.

5.2.1.3 STEP 3 Establish Accuracy Parameters

Accuracy parameters are established at the outset for several reasons. The accuracy to satisfy the end analysis requirements for which the data is collected. Accuracy parameters also aid in maintaining consistency of photo-interpretation results among several interpreters. Finally, the collection of superfluous data can be avoided, and thus can result in significant cost savings. Land use mapping accuracies may be approached at least three different ways: resolution, classification, and position.

Table 5.2.2

LAND USE CLASSIFICATION SYSTEM FOR USE
WITH REMOTE SENSOR DATA

LEVEL I	LEVEL II		ALPHA CODE
1. Urban and Built-up Land	11.	Residential	Ur
	12	Commercial and Service	Uc
	13	Industrial	Ui
	14	Transportation, Communications, and Utilities	Ut
	15	Industrial and Commercial Complexes	Ucc
	16	Mixed	Um
	17	Other	Ut
2 Agricultural Land	21	Cropland and Pasture	Ac
	22	Orchards, Groves, Vinyards, Nurseries, and Ornamental Horticutural Areas	Aor
	23	Confined Feeding Operations	Acf
	24	Other	Ao
3 Rangeland	31	Herbaceous Range	Rh
	32	Shrub-Brushland Range	Rs
	33	Mixed	Rm
4 Forest Land	41	Deciduous	Fd
	42	Evergreen	Fe
	43	Mixed	Fm
5 Water	51	Streams and Canals	Ws
	52	Lakes	Wl
	53	Reservoirs	Wr
	54	Bays and Estuaries	Wb
	55	Other	Wo
6 Wetland	61	Forested	Wlf
	62	Nonforested	Wln
7 Barren Land	71	Salt Flats	Bsf
	72	Beaches and Mudflats	Bbm
	73	Sandy Areas Other than Beaches	Bs
	74	Bare Exposed Rock	Br
	75	Strip Mines, Quarries and Gravel Pits	Bsm
	76	Transitional Areas	Bg
	77	Mixed	Bm
8 Tundra	81	Shrub and Brush Tundra	Ts
	82	Herbaceous Tundra	Th
	83	Bare Ground Tundra	Tb
	84	Wet Tundra	Tw
	85	Mixed	Tm
9 Permanent Snow and Ice	91	Permanent Snowfields	Ps
	92	Glaciers	Pg

(Source: U.S. Geological Survey Professional Paper 964)

Table 5.2.3 **LAND USE LEGEND**

AGRICULTURE

Each parcel of agricultural land use is labeled with a notation consisting basically of three symbols. The first of these is a lower case "i" or "n" indicating whether the parcel is irrigated or nonirrigated. This is followed by a capital letter and number which denote the use group and specific use as shown below.

C SUBTROPICAL FRUITS
1 Grapefruit
2 Lemons
3 Oranges
4 Dates
5 Avocados
6 Olives
7 Miscellaneous subtropical fruits

D DECIDUOUS FRUITS AND NUTS
1 Apples
2 Apricots
3 Cherries
5 Peaches and Nectarines
6 Pears
7 Plums
8 Prunes
9 Figs
10 Miscellaneous or mixed deciduous
12 Almonds
13 Walnuts

G GRAIN AND HAY CROPS
1 Barley
2 Wheat
3 Oats
6 Miscellaneous and mixed hay and grain

F FIELD CROPS
1 Cotton
2 Safflower
3 Flax
4 Hops
5 Sugar beets
6 Corn (field or sweet)
7 Grain sorghums
8 Sudan
9 Castor beans
10 Beans (dry)
11 Miscellaneous field

T TRUCK AND BERRY CROPS
1 Artichokes
2 Asparagus
3 Beans (green)
4 Cole crops
6 Carrots
7 Celery
8 Lettuce (all types)
9 Melons, squash, and cucumbers (all kinds)
10 Onions and garlic
11 Peas
12 Potatoes
13 Sweet potatoes
14 Spinach
15 Tomatoes
16 Flowers and nursery
18 Miscellaneous truck
19 Bushberries
20 Strawberries
21 Peppers (all types)

P PASTURE
1 Alfalfa and alfalfa mixtures
2 Clover
3 Mixed pasture
4 Native pasture

V VINEYARDS

R RICE

I IDLE
1 Land cropped within the past three years but not tilled at time of survey
2 New lands being prepared for crop production

S SEMIAGRICULTURAL AND INCIDENTAL TO AGRICULTURE
1 Farmsteads
2 Feed lots (livestock and poultry)
3 Dairies
4 Lawn areas

Special conditions are indicated by the following additional symbols and combinations of symbols.

A ABANDONED ORCHARDS AND VINEYARDS
F FALLOW (tilled but not cropped at time of survey)
S SEED CROPS
Y YOUNG ORCHARDS AND VINEYARDS
X PARTIALLY IRRIGATED CROPS

INTERCROPPING (or interplanting) is indicated as follows: $i\,\frac{D13\text{-}y}{T9}$ = a melon crop planted between rows of young walnut trees

URBAN

UC - URBAN COMMERCIAL

UC 1 Miscellaneous establishments (offices and retailers)
UC 2 Hotels
UC 3 Motels
UC 4 Apartments, barracks (three family units and larger)
UC 5 Institutions (hospitals, prisons, reformatories, asylums, etc., having a reasonably stable 24-resident population)
UC 6 Schools (yards mapped separately if large enough)
UC 7 Municipal auditoriums, theaters, churches, buildings, and stands associated with race tracks, football stadiums, baseball parks, rodeo arenas, etc.
UC 8 Miscellaneous high water use (indicates a high water use not covered above)

UI - URBAN INDUSTRIAL

UI 1 Manufacturing, assembling, and general processing
UI 2 Extractive industries (oil fields, rock quarries, gravel pits, public dumps, rock and gravel processing plants, etc.)
UI 3 Storage and distribution (warehouses, substations, railroad marshalling yards, tank farms, etc.)
UI 6 Saw mills
UI 7 Oil refineries
UI 8 Paper mills
UI 9 Meat packing plants
UI 10 Steel and aluminum mills
UI 11 Fruit and vegetable canneries and general food processing
UI 12 Miscellaneous high water use (indicates a high water use not covered above)

UV - URBAN VACANT

UV 1 Miscellaneous unpaved areas
UV 4 Miscellaneous paved areas

UR - URBAN RESIDENTIAL

One and two family units, including trailer courts

RECREATION

RR RESIDENTIAL
Permanent and summer home tracts within a primarily recreational area. (The estimated number of houses per acre is indicated by a number in the symbol.)

RC COMMERCIAL
Commercial areas within a primarily recreational area (includes motels, resorts, hotels, stores, etc.)

RT CAMP AND TRAILER SITES
Camp and trailer sites in a primarily recreational area

P PARKS

NATIVE

NV NATIVE VEGETATION

NR RIPARIAN VEGETATION
NR 1 Swamps and marshes
NR 2 Meadowland

NW WATER SURFACE

NC NATIVE CLASSES UNSEGREGATED

(Source: The State of California, The Resources Agency, Department of Water Resources)

Table 5.2.4

LAND USE CLASSIFICATION SYSTEM FOR PLANNERS

(Source: Urban Renewal Administration (URA-(HUD))
(and Bureau of Public Roads (BPR)- U.S. Govt.)
(Modified by San Diego, Calif. County Planning Dept)

LAND USE

- **1. LIVING AREA (Residential)**
  - 10 Living Area Undiff
  - 11 Single Family Dwelling (Med D)
  - 12 Multiple Fam Dwell (High D)
  - 13 Urban Estate (Low Density)
  - 14 Mobile Home Pks & Trl Ct
  - 15 Transient Lodgings
  - 16 Rural Dwelg (Low Density)
  - 17 Mtn Dwelling (Low Density)
  - 18 Supplemental Residential
  - 19 Residential NEC
- **2,3 MANUFACTURING**
  - 20 Manufact., Undiff.
  - 21 Food Products
  - 22 Textile Mill
  - 23 Apparel & Other Finish
  - 24 Lumber & Wood
  - 25 Furniture & Fixtures
  - 26 Paper & Allied Pdct
  - 27 Printing & Publishing
  - 28 Chemical & Allied
  - 29 Petroleum Ref & Relt
  - 31 Rubber & Misc Plastic
  - 32 Stone, Clay & Glass
  - 33 Primary Metal Ind
  - 34 Fabricated Metal Prod
  - 35 Prof, Sc Inst, Photo
  - 39 Manufact NEC
- **4 TRANSPORTATION COMMUNICATION & UTILITIES**
  - 40 Tr, Com, Ut Undiff
  - 41 Railroad, Rl Tr, St RY
  - 42 Motor Trans Facilities
  - 43 Aircraft Facilities
  - 44 Marine Craft Fac.
  - 45 Highway & St Right-way
  - 46 Automobile Parking
  - 47 Communications Fac&Cor
  - 48 Utilities Fac &Cor
  - 49 Tr, Com, Ut NEC
- **5 TRADE, WHOLESALE, RETAIL**
  - 50 Trade Undiff
  - 51 Wholsale Trade
  - 52 Retail Tr Bldg & Hardw
  - 53 R.T. General Merchandise
  - 54 R.T. Food
  - 55 R.T. Auto Marine, A/C
  - 56 R.T. Apparel
  - 57 R.T. Furniture & H.F.
  - 58 R.T. Eat & Drink
  - 59 Trade NEC
- **6 SERVICES**
  - 60 Services, Undiff
  - 61 Finance, Ins, R.E.
  - 62 Personal Services
  - 63 Business Services
  - 64 Repair Services
  - 65 Profession Services
  - 66 Contract Const Serv
  - 67 Government Services
  - 68 Educational Services
  - 69 Services Social
- **7 CULTURAL, ENTERTAINMENT & RECREATION**
  - 70 Cul, Ent, Rec Undiff.
  - 71 Cul Act & Nature Ex
  - 72 Public Assembly
  - 73 Amusements
  - 74 Recreation Activities
  - 75 Resorts & Grp Camps
  - 76 Parks
  - 79 Cul, Ent, R NEC
- **8 RESOURCE PRODUCTION & EXTRACTION**
  - 80 Resources Undiff
  - 81 Agriculture
  - 82 Agricultural Related Act
  - 83 Forestry Activities
  - 84 Fishing Activities
  - 85 Mining Activities
  - 89 Resources, NEC
- **9 UNDEVELOPED LAND AND WATER AREA**
  - 90 Undeveloped Undiff.
  - 91 Undeveloped Unused Land
  - 92 Noncommercial Forests
  - 93 Water Areas
  - 94 Vacant Floor Area

a. Resolution Accuracy

Resolution accuracy refers to the smallest area on the ground which is considered to be a distinct land use and is to be delineated as such. For example, if the resolution accuracy is one acre, any differentiable land use with an areal extent of less than one acre is not mapped, but is considered to be an integral part of the surrounding use.

Resolution accuracies may be applied differentially but systematically throughout the study area. In regional applications, urban areas are often mapped at a greater resolution than the surrounding rural areas. Decisions whether or not to map linear features are usually determined by linear distance of the features cross section, such as the width of a road, as opposed to actual areal parameters.

b. Classification Accuracy

Classification accuracies describe the ability to correctly determine the land use according to the chosen classification system and the hierarchical level within that system. That is to say, if a classification accuracy of 90% was established, for any sample of delineated parcels the assigned land use should be correct at least 90% of the time. Because the assignment of land use to a classification system element is sometimes a value judgement, this accuracy term is not precisely measurable. It should be established though and is often included in private contracts as the primary means of determining accuracy.

c. Positional Accuracy

Position refers to the relation of delineated boundaries with some specific geographic reference system. If the land use map will be used to summarize land use by area measurement and the accuracy of results is to be within 2% of reality, then a base map that is accurate to 2% tolerance is required. The United States Geological Survey publishes maps certified to a ground accuracy of 2 feet (.7 meters). Base maps with this accuracy will provide adequate control to enable area measurements acceptable to most planners. However, if a generalized map is being prepared to assist in zoning or management matters that do not require areal measurments, or is not to be registered with other map data, then more distortions may be acceptable.

5.2.1.4 STEP 4 Select Data Source

Before the development of aerial photography it was necessary to acquire data by actual field survey. For detailed urban mapping to the fourth level of classification the field survey method may still be the most desirable. However, for much rural and mountainous land use mapping the field survey is inadequate because it is difficult to see far from the observation point. Thus many areas on the resultant land use map are only accurate near the transect line.

Today we have the advantage of diverse platforms that provide several types of images for multiple dates or time periods. The aerial image enables large regions with poor accessability to be mapped with a high degree of accuracy. Data for land use mapping from remotely sensed imagery has become

a normal acquisition method and the field survey is used for accuracy checking. Suitable scale imagery can fulfill most of the data requirements to a third level of classification and sometimes even to lower levels. For example, if the classification system requires knowledge of the composition of types of businesses in high rise buildings in the central business district, then imagery is not the total solution.

The two methods of data acquisition used in combination present the most complete solution to land use mapping. Imagery can provide the basis for boundary determination as well as establishing land use to the second and third levels of classification. To verify questionable areas of interpretation it is essential to perform a ground survey. Any urban detail, such as distinguishing between retail and wholesale trades (which are not detectable from imagery), must be resolved from the field survey.

5.2.1.5 STEP 5 Select the Scale and Type of Imagery

Many government agencies have acquired various types of remotely sensed imagery from research projects conducted in the past several years. Copies of selected imagery are available to the general public. Because of the vast quantities of available imagery, selection has become more complicated than just planning a flight for a private aerial survey firm. The task becomes one of finding and obtaining imagery that is available and suitable, in scale and type.

a. Scale and Ground Resolution

The level of classification will determine the needed ground resolution. One factor to keep in mind when selecting imagery, whether from a library or special aerial survey, is that the smaller the resolution the greater will be the acquisition cost. It is often possible to work with imagery at less resolution than might otherwise be thought. As an example a project may be established to ascertain beach attendance on a Sunday afternoon in the summer. The first reaction is to acquire imagery that can detect a person walking on the beach. This would require ground resolutions of less than .3m (1 foot). Obtaining this type of resolution would normally require the imagery to be at a scale of between 1:2,000 and 1:3,000. Perhaps the beach attendance could just as well be established through a surrogate process. In this case automobiles parked at the beach may act as the surrogate if the ratio of people per car can be established for the particular location. To detect an automobile requires a ground resolution of only 3m (9-10 feet). Imagery obtained at a scale of 1:24,000 can easily provide this information. The cost of the smaller scale imagery would be considerably less since the same format imagery at a smaller scale can image a much larger land area and thus requires fewer frames of film.

Another scale consideration relates to the rectification required to produce a planimetric map. Having the original image produced at the same scale as the base control map may provide a cost savings in the data transfer process. The United States Geological Survey publishes a topographic series of maps at a scale of 1:24,000 that provides excellent planimetric control. Imagery acquired at the same scale enables the transfer of data simply by overlaying the image on the base map. When selecting imagery from the government libraries it may be necessary to compromise on the scale and ground resolution to take advantage of the cost savings provided by the advantage of not paying for original acquisition costs.

b. Platform

The selection of the platform utilized to acquire the imagery will have been pre-established if the imagery is being acquired from government sources. Some selectability is available if new imagery is being acquired from a private aerial survey company. Low altitude and some medium altitude aircraft flights are available from private sources. High altitude aircraft flights and satellite platform data are available from government sources only. The definition of platform altitudes and attendant scales for purposes of this manual are:

PLATFORM ALTITUDE	RELATIVE SCALE NORMALLY OBTAINED
Low Altitude (5-15,000 ft)	1:1,000 to 1:12,000
Medium Altitude (15-45,000 ft)	1:12,000 to 1:30,000
High Altitude (60-70,000 ft)	1:30,000 to 1:250,000
Satellite (100-600 mi)	over 1:250,000

c. Format and Type of Imagery

Imagery available from government sources includes various formats and types of imagery. Film or print formats range from 70mm "chips" to 9" x 9" aerial roll film format. Prints, negatives or positive film, are available in black & white, natural color, color infrared imagery, or thermal infrared as well as film produced from a few other types of sensors. In addition, multispectral imagery is available in both digital and film formats. If the vast collection of imagery held by government sources cannot meet individual requirements, then a locally contracted survey must be planned. Under the latter circumstances the planner must still decide the type of imagery and format considered in light of their costs. Detailed discussions of the various types and abilities of film can be found in the Manual of Remote Sensing (Slater, 1976).

5.2.1.6 STEP 6 Establish Base Mapping System

The choice of a base map to be used in controlling the drafting of the work map is dependent upon the required accuracies. The base map should contain cultural details (i.e. roads or other significant points) that can be related to features detectable on the image. The features should be spread throughout the map so that the image detail can be rectified to the planimetric map base. If cultural features are not available on the map it is sometimes possible to use natural features that maintain a high degree of stability. Many stream beds are found to hold their positions over the period since the most recent USGS topographic map was made.

In the United States it has been found that the most suitable base maps are published by the United States Geological Survey. Three series of topographic maps are published at scales of 1:24,000; 1:62,500; and 1:250,000 (USGS, 1969). At a cost of $1.25 per sheet the maps are relatively inexpensive and can be obtained for any area in the United States in at least one of the three different scales. Distribution centers are located throughout the U.S. including the Map Distribution Center, USGS Denver Federal Center Bldg 41 Denver, CO 80225.

If area calculation is not a concern, then base map selection is not critical. In this case a suitable base map may even include an ordinary road map, or a map included in a standard atlas. However, the latter maps create a copyright problem and cannot be reproduced without permission. Most government maps are not copyrighted, which makes the choice of USGS maps perhaps the most acceptable map to use for all cases.

5.2.2. Mapping Phase

The actual production of the work map involves the transfer of the relevant data from the image to the initial work map. If a planimetric map is required, the data transfer process must be controlled by utilizing an accurately prepared base map such as a USGS topographic map. Planimetric control is normally obtained manually by overlaying the work map (a sheet of frosted mylar drafting film) on the base control map. Lines drawn on the mylar work map can then be controlled by the cultural features seen on the base map. Automated systems have been developed that maintain accurate planimetric control by utilizing a procedure called electronic resectioning (Tewinkel, 1966). The data transfer process involves the procedures of: scale change, image rectification, boundary interpretation, land use interpretation, and a random field check for verification of accuracy and correction of uncertain interpretations. (See details below.)

5.2.2.1 STEP 7 Selection of Scale Change and Image Rectification Method

a. The Manual Method

The method of data transfer that has been employed for centuries applies equally to image data transfer and involves the overlay of the work sheet on the base control map and visual transfer of the data. The image is studied for certain identifiable cultural features such as roads and highways. The same roads and highways are identified on the base map and lines are drawn where land use boundaries are desired. Boundaries along fence lines, or other differentiating land use boundaries which do not appear as cultural features on the base map, are drawn by interpolating the distance between detectable cultural features. The manual process accounts for the necessary scale changes and rectifies the distortions present in most images.

b. The Projection Method

Another common method of transferring data from the image to a work map has been to project the image onto the work map. Some advanced projection devices have been developed such as the Bausch and Lomb Zoom Transfer Scope which uses the camera-lucinda technique of projecting the image and the base map similtaneously onto the same eyepiece by use of mirrors. Several other types of image enlarging and projecting equipment are commercially available. Perhaps the simplest method is to use an ordinary projector either through a glass screen or against a matte surface on the wall. All of the projection systems require that the work map overlay the control base map -- or that significant control features are copied onto the work map. If the projection is through a glass onto the work map (i.e. rear projection) it becomes impossible to place an opaque base control map between the work map and projector. In this event it becomes essential that control features are sketched on the work map from the base control map before the projection process begins.

c. <u>The Photo Reduction/Enlargement Method</u>

The advent of inexpensive matte surface photo film bases, developed by the ammonia process (e.g. DuPont CFM-4 Cronaflex Projection Film), has made the technique of photo reduction/enlargement a more accepted, accurate, and cost effective method of image-to-map data transfer. Either the base map is photographically reduced to the image scale or the image is photographically enlarged to the base map scale. The process provides a black-and-white transparent film that can be overlayed by either image-on-base map or base map-on-image.

5.2.2.2 <u>STEP 8 Interpret and Transfer of Land Use Data from Image to Work Map</u>

Using the base map for control the next step is to establish boundaries for each land use type, interpret the land use classification, and produce a planimetric work map.

The boundaries can be quickly established by overlaying the reproduced map transparency on the image (or the scaled film image over the base map), and drawing appropriate lines between the various land use types.

Interpretation can proceed at the same time that boundaries are being drawn. However, some interpreters find it convenient to do the interpreting separately using a magnifier to get a better "look" at the image data.

Planimetric control is provided by the cultural features on the base map; these can be utilized as boundaries where indicated. The natural camera distortion encountered in most images can be rectified by slight adjustment of the overlay. When boundary lines fall between two cultural features of the base maps (e.g. roads) then a slight adjustment may be necessary to interpolate the correct distance between the roads that bound the area. A set of variable calipers with 10 divisions is a useful tool in estimating distances between points.

Certain regions of the world, such as the Western United States, have accurate survey control where land is divided into square mile sections. Quite often property lines fall on even divisions of these sections (e.g. 1/8, 1/4, or 1/2 mile divisions). Using common sense, it becomes a simple procedure to locate accurate boundary lines.

5.2.2.3 <u>STEP 9 Conduct Random Field Check of the Completed Work Map</u>

The accuracy of interpretation is a critical part of the land use mapping process. Even the most experienced interpreter has occasional problems with poorly defined features on the image. The questionable interpretations should all be field checked for correctness. In addition a random sample of interpreted features should be checked in order to establish the classification accuracy of the map. This accuracy should be noted on the final product.

5.2.3 <u>Data Compilation and Presentation Mapping Phase</u>

5.2.3.1 <u>STEP 10 Select Method of Reproduction and Statistical Compilation</u>

Upon commencement of this phase a draft land use map should be completed. The map is essentially planimetrically correct and consists of a set

of connected boundaries (polygons) and associated land use attributes. It is also assumed that the assigned land use is homogeneous throughout each individual land use polygon. The map is only a 'draft' map and as such is not in a presentable or publishable condition. One may choose to prepare the map using common cartographic procedures or the map may be converted to machine format for further automated statistical manipulation and mapping.

The decision to complete the map manually or to convert to machine format should be based upon the ultimate use of the map data. The time involved in conversion of a draft map to computer format is approximately the same as that involved in manual completion. If accurate area calculations are required, or the map is to be continually updated, or the land use data are to be combined with other data (e.g. census information) then justitication exists for conversion to machine format.

5.2.3.2 STEP 11 Prepare a Clean Copy of the Land Use Map

Whether the final map is produced manually or by machine procedure, a "clean" map will be required for further processing. In manual production the "clean" copy often is obtained by inking in the boundary lines and cleaning up the other areas with various drafting techniques. In machine processing there are several considerations. The degree of cleanness depends upon the method of data conversion.

If the work map was produced on mylar film with all the shades of gray of the original image, or all the topographic features of the contour lines, then the line work must be extracted from the background. In many cases the only reasonable solution is to redraw the boundary lines on a clean mylar overlay. Using a light table this procedure can be accomplished rapidly.

In addition to removing unwanted detail on the work map it is also necessary to provide additional data conversion information for machine processing. One method of data conversion is for an operator to digitize each line segment of the work map. If each polygon is digitized independently the result is double digitizing. That is the line segments are digitized twice; once for each adjacent polygon. This presents no problem at the intersection of lines. However, where a line segment bends the operator must know where to locate a vertex point for that bend so that he digitizes the same location for both adjacent polygons. Hence, the preparation of a "clean" map copy for machine conversion may also include placing tic marks on any line segment that changes direction other than at the intersection of two or more lines.

5.2.3.3 STEP 12 Convert "Clean" Work Map to Machine Format

The remainder of discussion in this phase considers the problems of machine production of land use maps because manually produced maps would be completed at the end of step 10.

a. Machine Digitizing

The conversion of a map to machine format can be accomplished in several ways including manual conversion utilizing a coordinate overlay, or through the use of any one of the many machine scanners or line followers which have been developed. The discussion will be limited to manual conversion procedures using a coordinate table.

A commonly used device for map data conversion is a coordinatograph. This is a table and associated electronics that will measure the X and Y coordinates of a point from a pre-set origin to accuracies of one-hundredth (0.01) of an inch to ten-thousandths (0.0001) of an inch. The finer the resolution of measurement the costlier the machine. Most land use or thematic map data conversion can be accomplished with a resolution of one-hundredth (0.01) of an inch. By means of mechanical and optical encoders the analog map data are transferred to electronic equipment that converts the analog measuring signal to a digital machine readable form.

b. Procedural Error Editing

Both time and money can be saved if the raw converted map data is subjected to a preliminary edit procedure. The edit is designed to detect procedural errors that are caused by the human operator. Most of the human errors are excusable because digitizing is a tedious task and requires close concentration with considerable eye-strain occurring during the process. The visual editing of converted data is laborious, time consuming and inaccurate. A computer editing program performing the same operations takes about 30 seconds time (even for a detailed map) and detects all procedural errors. For example, if the operator failed to close a polygon (return to the original starting point) the program will detect that condition, which would otherwise lead to an ambiguous situation. The operator must then correct the errors. of the same data may take one to two hours and not necessarily detect all the errors.

c. Geometric Editing

Once the raw data has been edited and corrected a test map must be plotted. The test map is then edited for geometric errors in digitizing that occur either through machine failure or operator error. If the operator fails to locate the same point within a set selected tolerance (0.01" to 0.03") a double line may be created bordering adjacent polygons. This error is apparent on the test map as a double line. Overlaying the test map on the "clean" work map will detect the error. The double line may also create a calculation error in determining the area of a polygon. Occasionally the conversion equipment will malfunction and not record the correct X or Y coordinate, or the computer will be unable to read a coordinate and substitute a zero value. A "spike" will be created which causes the plotter to draw a line from its last position to some distant point on the map. When all the geometric errors are corrected then final map production can begin.

5.2.3.4. STEP 13 Produce Statistical Tabulation of Land Use Data

One purpose for machine production is to be able to accurately compute the land use areas. Once the final edit and corrections have been made, the area data can be generated with assurance of accuracy (i.e. less than 1% error in computed area). Digital computers permit rapid computation of areas for individual polygons. In addition, a more useful tabulation is a compilation of total area for each land use classification present on the map.

5.2.3.5 STEP 14 Produce Final Land Use Maps

The final step in land use or thematic map production is to draw or plot a shaded or colored map - commonly called a choroplethic map. The computer must be instructed as to which shade and/or color is to be placed in each polygon. Reference should be made to any one of several standard cartography textbooks for the theory to shade and coloring techniques. Generally the feature to be emphasized will have the densest shade or be selected from the red end of the color spectrum.

Some computer programs will produce part or all of the map legend, otherwise legends must be added manually. Titles and subtitles are an essential part of a map. Each map should have a scale. If the map is to be photographically changed in scale then a graphic bar is the only scale that can be placed on the map. Other types of scales (e.g. representative fractions) lose their meaning when the map is photographically reduced or enlarged.

There can be several overlay features added to the final map, either manually or by computer. If a user needs a road network for a reference system, it can be drawn in by machine or manually. Other reference areas such as place names can be similarly added.

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5.3 Current Study: Irrigated Agriculture Change Detection in the Upper Santa Ana Basin

5.3.0 Introduction

The California Department of Water Resources (DWR) maps land use on a ten year cycle. These mappings include agriculture and provide the basis for all agricultural water demand estimates. Changes that occur between mappings go undetected, and they can be substantial in the urbanizing southern California environment.

The DWR estimates their areal mapping accuracy at 98%, an accuracy that would be difficult if not impossible to duplicate from LANDSAT, in its present configuration. If, however, the DWR is provided with an annual update of irrigated (and, conversely, non-irrigated) land at an accuracy of 90-95%, they would find that information useful in their water demand estimations. In order to assist the DWR to more effectively determine agricultural water requirements, the Riverside Campus is attempting to determine annual changes in irrigated agriculture within the southern California test site.

5.3.1 The Study Area

Agriculture in southern California is quite varied and includes irrigated and dry-farmed grains, vegetable crops, permanent tree crops, and improved and unimproved grazing lands. Multiple cropping (raising more than one crop per year on a given field) is a common practice, especially with the vegetable crops. Dry-farmed grain fields are usually left fallow every other year. Some grains are prematurely cut (green chop) for hay. A wide variety of cultural practices combines to present complex agricultural patterns. Nowhere in southern California is this entire melieu of cultural practices better represented than in the Perris Valley.

Figure 5.3.1 is a June 1975 Landsat image of the Perris Valley area (identified by the numerous agricultural fields). The Perris area is sited on what is commonly referred to as the Perris Block, a relatively homogeneous surface that has been uplifted by faulting. The San Jacinto Fault and the Elsinore Fault delineate the Perris Block with their traces trending northwest-southeast. The northeast and southwest borders are defined by the Santa Ana River and a low upland complex, respectively.

Agriculture in Perris Valley is confined primarily to areas of alluvial fill. Irrigated and non-irrigated agriculture are mixed throughout the area with the non-irrigated lands being found primarily on the more rolling topography. In the northwest part of the Perris Block, granitic outcrops of the southern California batholith preclude significant agriculture; citrus, however, is found in the more favored areas.

5.3.2. Methodology

The Perris Valley was field mapped by the DWR in August 1975, and a 100% field check was done for the entire area. This information is considered to be 'correct' and will be used for evaluating any detected changes. Unfortunately, suitable Landsat and U-2 imagery do not match the date of the DWR survey. Landsat imagery from June 1974 and 1975 is being used in the initial experiment. U-2 underflights from March and June 1974 are available and are being used as collateral data. It is assumed that the June imagery will approximate data on the DWR

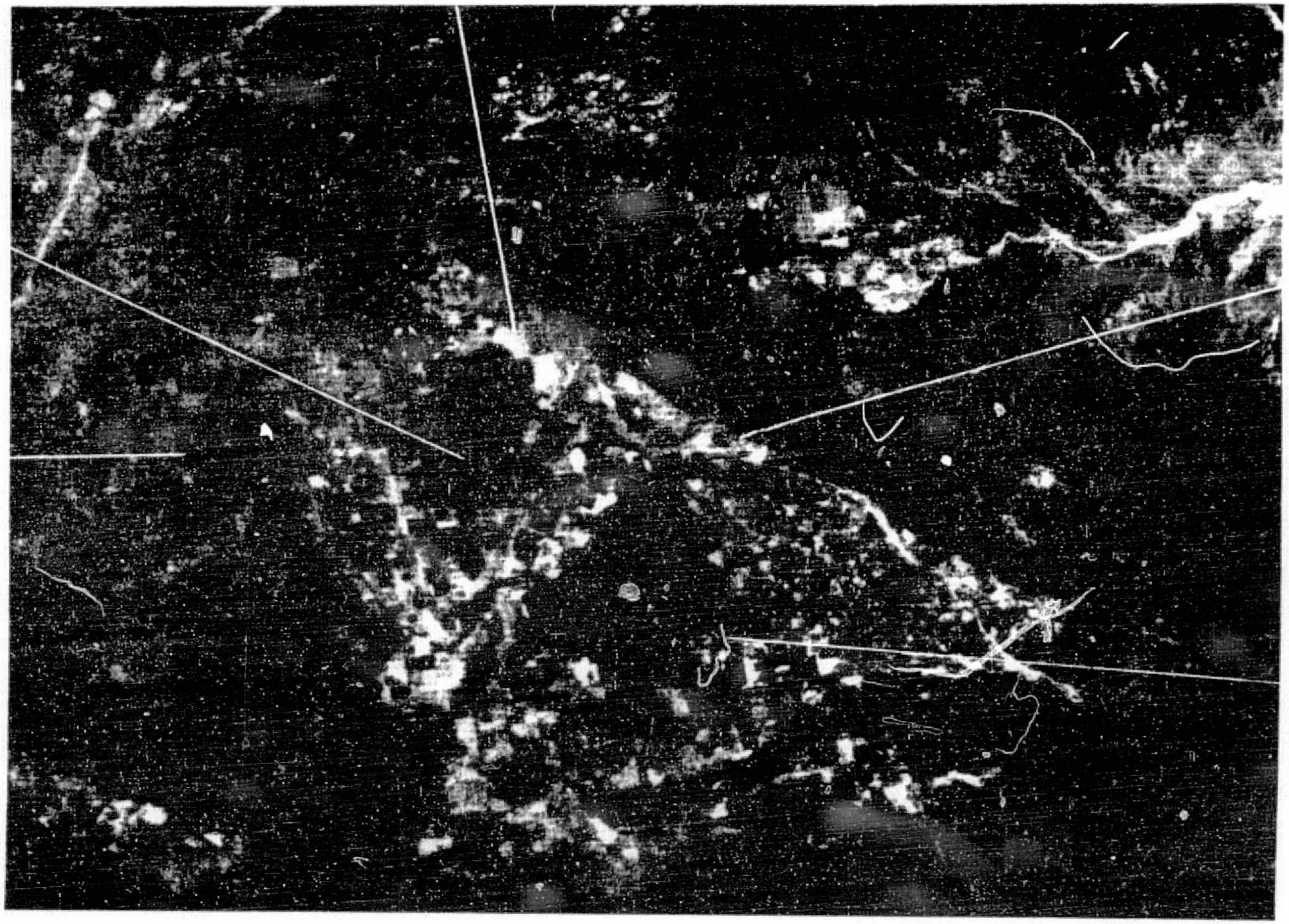

Figure 5.3.1 An enlarged portion of June 1975 Landsat imagery. The figure focuses on the agricultural test site of the Perris Valley.

maps. A crop calendar is being developed that will allow for the determination of likely crop changes during the June to August period.

Preliminary investigation has shown that if an irrigated field changes to a non-irrigated one, the change will likely be to either dry-farmed grain, fallow land, or to an urban use. Conversely, non-irrigated land can change to any irrigated classification or to urban. The main problem appears to be in systematically ignoring changes from one irrigated crop to another. It should be stressed that actual crop identification is not of primary concern. Rather this methodology seeks to identify agricultural changes which can be checked on the ground or with suitable scale imagery resulting in a quick low-cost updating procedure.

5.4 Current Study: Utilization of Remote Sensing to Provide Inter-Census Population Estimates

Water demand can be divided basically into urban and agricultural uses. For estimating present urban water consumption, DWR utilizes population data and water delivery data for service districts to arrive at a per capita water use statistic. Over time these statistics yield water consumption trends which may then be used to extrapolate future water demand. This technique cannot be applied to agricultural water use because population has no relevance. For purposes of urban water demand estimation, however, this procedure is proving quite useful but has limitations for some planning purposes because of the aggregated nature of the data.

5.4.1 Urban Per Capita Water Demand Estimation

The urban per capita water use estimation method is a set of procedures which establishes a gallons-per-capita-per-day (gpcd) figure for urban and industrial water uses in each water service district. Its applicability is limited to those service districts where reliable population and delivery estimates are available. Procedures employed by DWR are: 1) Annual Deliveries are calculated and include metered municipal and industrial use plus system losses minus agricultural use and water sold to other utilities; 2) Population for a given year is calculated by deriving persons per water service connection and/or persons per dwelling unit from census data, which is interpolated between census years and multiplied by the number of water service accounts or dwelling units. Where census data are not available, population estimates are provided by the water agency itself. Therefore, annual water production in terms of gpcd is given by the following equation:

$$\text{gpcd} = \frac{\text{Annual Production (gal/yr)}}{\text{Population}} \quad \text{X} \quad \frac{1}{\text{days/yr.}}$$

Straightaway one may see that the above procedure relies heavily on population data and/or dwelling unit counts for accurate estimates. On the whole, DWR analysts feel that intercensal population estimates, which are made by the State Department of Finance, cities themselves, and water service districts on a new connections basis, are adequate for most highly aggregated long-term projections. However, these analysts have expressed a need for knowing where this population exists so that proper estimates can be made in the context of DWR's hydrological sub-unit planning areas, as well as other arbitrary aggregation units. In order to accomplish this disaggregation the spatial patterns of population must be established. This is accomplished most readily by remote sensing techniques.

5.4.2 Estimation of Population Using Remote Sensing

One study currently in progress addresses the need to analyze water use on a per capita basis and demonstrates the combination of data from the decennial census and high-altitude color infrared imagery. At least one value of this combination of data is the amplification of its geographic component. For example, it would be useful to show not only the extent of each census tract and its population aggregate but the actual area within each census tract that is occupied by various forms of land use. Specifically, remotely sensed data provides information which can be used to delineate land area used for housing and land area used otherwise.

Making a few assumptions about population dynamics it is possible to depict the changes in population for a small area in both positive and negative amounts. The first assumption is that the per dwelling unit population density within a census tract will not change rapidly. The second assumption is that the population density is proportional among the contiguous residential land use areas of a particular census tract. The utility of these assumptions is that by defining a density population statistic the total population of any planning unit, i.e. hydrologic subunit, fire district, school district, etc. can be obtained by summing the population of all of the residential areas contained within that planning area. For residential areas which are split by planning area boundaries the per capita density figure will reveal the expected number of persons in that part of the residential unit which occurs within that planning area; information which can only be estimated relative to area. Also, intercensal population can be estimated by simply evaluating an image of the area taken at the time in question and by applying the old population density to the more recent housing pattern.

In order to test the above assumptions and the accuracy of inter-censal population estimation an experiment was carried out utilizing 1970 and 1975 census data for a portion of San Bernardino, California. The 1970 census data were derived from U.S. Census Bureau sources. The 1975 census data, which were used to check accuracies, were available as a result of a special census carried out by San Bernardino County. The study area covers twenty-seven census tracts which include high and low density housing, commercial and industrial uses as well as * areas of housing expansion and housing abandonment. Figure 5.4.2 is a U-2 image of the study area.

The methodology employed involved the comparison of 1970 and 1975 housing areas as mapped from high altitude NASA imagery and the extrapolation of population density from 1970 to 1975 (Fig. 5.4.1). Three maps were produced, one of census tract boundaries from an existing basemap and two from the housing interpretaion. Housing was delineated from CIR 1:130,000 scale transparencies. In order to insure registration accuracy these frames were enlarged to a nominal scale of 1:62,5000 and black-and-white Cronaflex images were produced. The housing area boundaries were then transferred to mylar sheets overlaid on the Cronaflex. Census tract boundaries were established on the same basemap. All three maps were then digitized for computer overlay processing. After creating a grid cell image of each map the cells were aggregated into housing and non-housing counts for each census tract for both years. Figure 5.4.3 shows the census tract boundaries overlaid on the 1970 housing image. The acreage value per grid cell was multiplied by the cell counts to give acreage tallies. Census data for 1970 were used to calculate density values at the tract level. The density values were then applied to the

POPULATION ESTIMATION FLOW DIAGRAMS

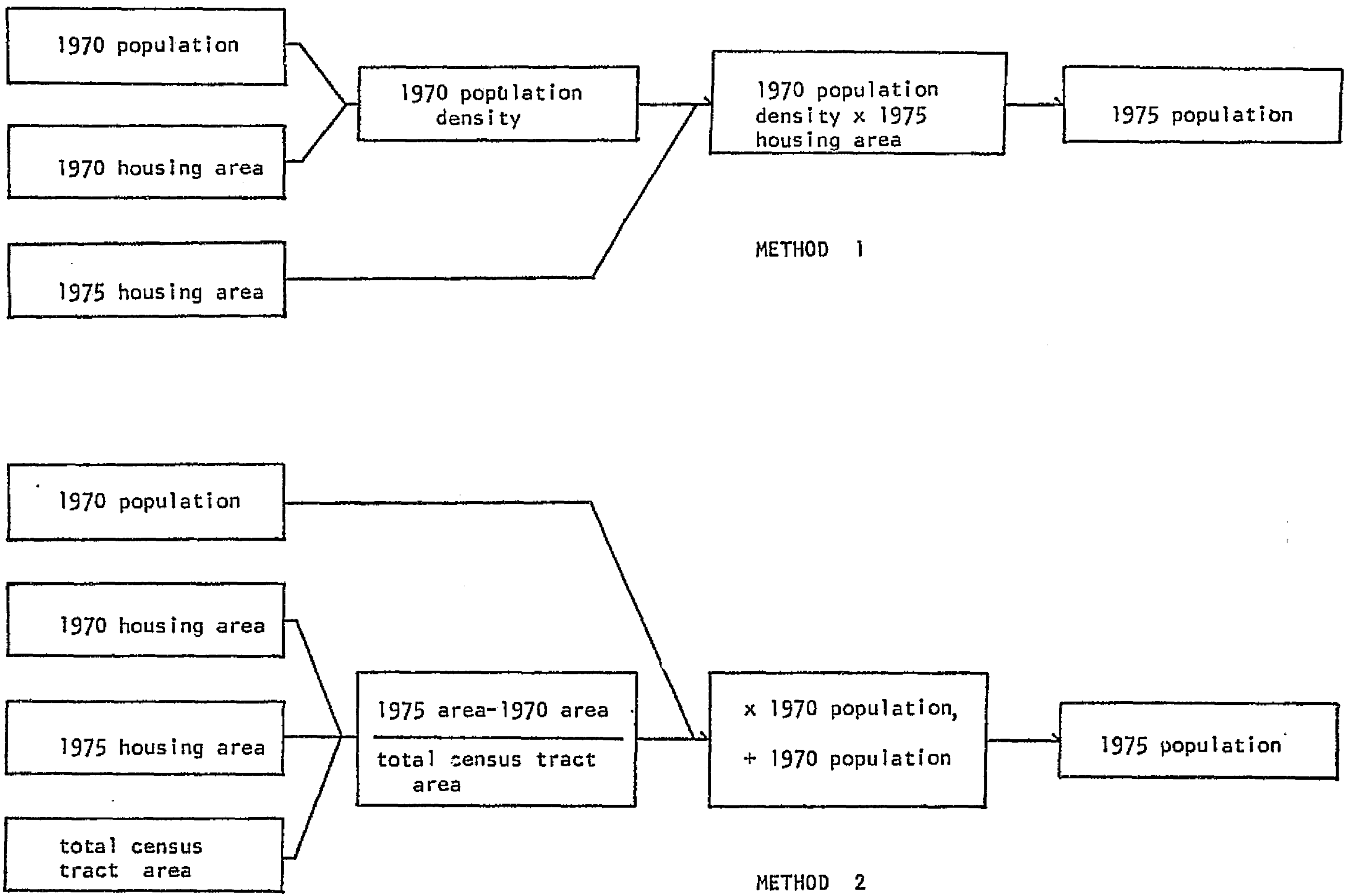

Figure 5.4.1

Figure 5.4.2

U-2 Image of San Bernardino Showing Study Area Outline

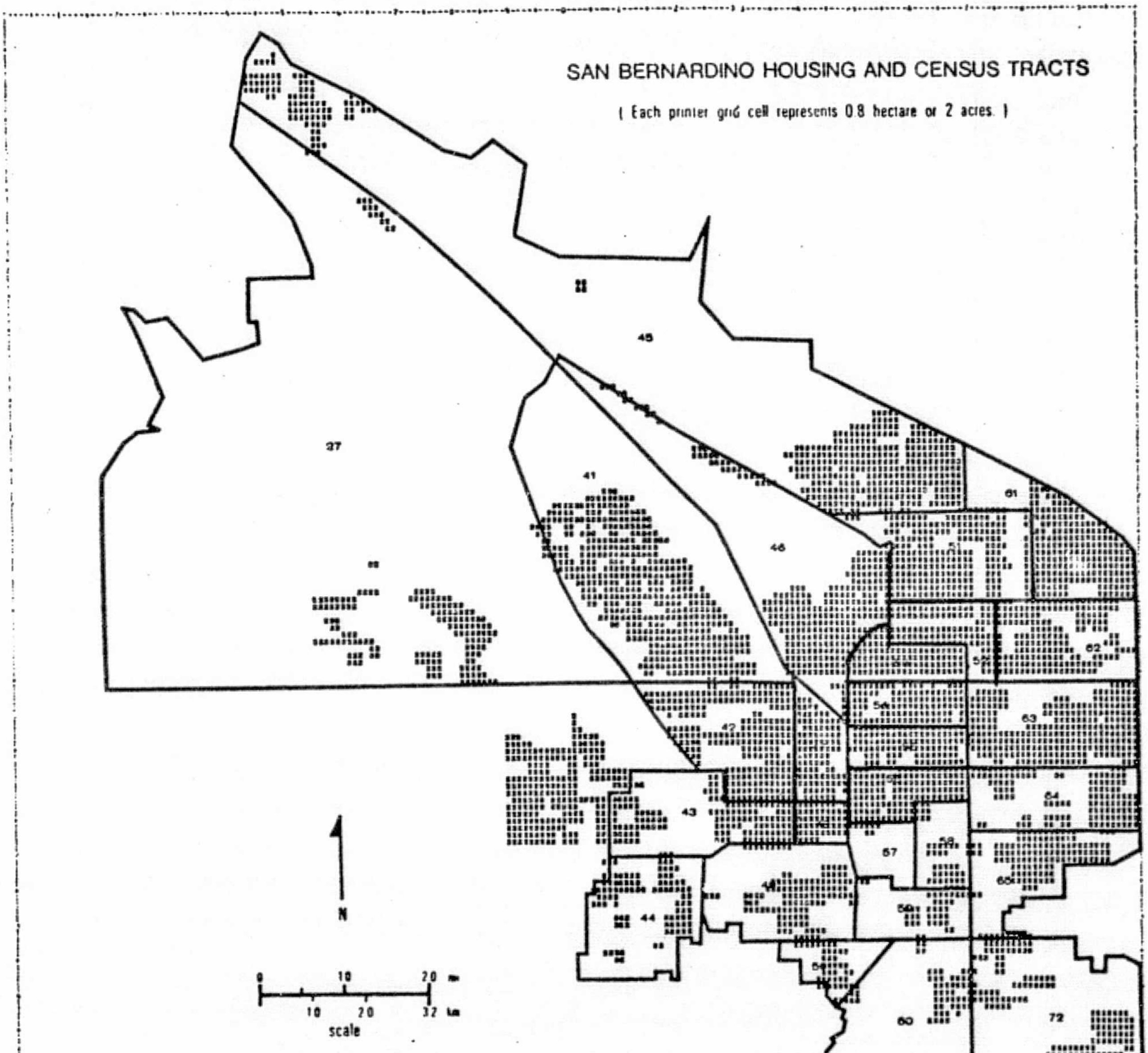

Figure 5.4.3

San Bernardino 1970 Housing and Census Tracts . (Compare with Figure 5.4.2.)

CENSUS TRACT NUMBER	POPULATION	1970 ACRES OF HOUSING	1970 PERSONS PER ACRE	1970 HOUSING TOTAL ACRES	1975 ACRES OF HOUSING	1975 PERSONS PER ACRE	1975 HOUSING/ TOTAL ACRES	CHANGE 1975-1970 ACRES OF HOUSING	CHANGE 1975-1970 PERSONS PER ACRE	CHANGE 1975-1970 HOUSING/ TOTAL ACRES	CHANGE 1975-1970 PERSONS PER D.U.
27	3743	490	7.64	.0300	592	6.54	.0363	102	-1.10	.0063	-.37
41	9264	1572	5.89	.3861	1746	4.38	.4288	174	-1.51	.0427	-.34
42	9714	722	13.45	.6224	810	10.33	.6983	88	-3.12	.0759	-.48
43	7375	520	14.18	.4602	562	11.49	.4973	42	-2.69	.0371	-.35
44	5093	324	15.72	.2727	336	12.01	.2828	12	-3.71	.0101	-.40
45	11139	1396	7.98	.1824	1466	7.01	.1916	70	-.97	.0092	-.40
46	8059	814	9.90	.2889	904	8.12	.3208	90	-1.78	.0319	-.16
47	4974	376	13.23	.7402	388	10.85	.7638	12	-2.38	.0236	-.38
48	2755	192	14.35	.8496	202	11.77	.8938	10	-2.28	.0442	-.28
49	4061	382	10.63	.3162	390	9.92	.3228	8	-.71	.0066	-.09
50	1971	130	15.16	.3714	138	11.59	.3943	8	-3.57	.0229	-.27
51	6842	828	8.26	.6656	798	8.03	.6415	-30	-.23	-.0241	-.30
52	3304	350	9.44	.7353	360	8.88	.7563	10	-.56	.0210	-.37
53	3997	394	10.15	.8603	370	9.70	.8079	-24	-.45	-.0524	.20
54	3681	374	9.84	.8348	370	9.89	.8259	-4	.05	-.0089	-.03
55	4767	372	12.81	.8304	372	11.91	.8304	0	-.90	0	-.10
56	4775	386	12.37	.7942	376	10.97	.7737	-10	-1.40	-.0205	-.09
57	912	48	19.00	.1500	52	16.23	.1625	4	-2.77	.0125	.03
58	2204	166	13.28	.3756	204	10.34	.4615	38	-2.94	.0859	-.69
59	1253	154	8.14	.2628	96	10.54	.1638	-58	2.40	-.0990	-.22
60	1013	164	6.18	.0873	192	4.27	.1022	28	-1.91	.0149	-.21
61	8953	876	10.22	.7180	872	9.44	.7148	-4	-.78	-.0032	-.38
62	7349	642	11.45	.6114	674	10.99	.6419	32	-.46	.0305	-.41
63	10942	942	11.62	.7009	924	10.18	.6875	-18	-1.44	-.0134	-.13
64	4813	468	10.28	.4286	472	9.70	.4322	4	-.58	.0036	-.41
65	3662	420	8.72	.4555	436	7.21	.4729	16	-1.51	.0174	.06
72	4508	634	7.11	.2548	736	6.23	.2958	2	-.88	.0410	-.24

TABLE 5.4.1

Census Tract Data for Selected San Bernardino Census Tracts

TRACT NUMBER	1975 POPULATION*	METHOD 1 ESTIMATED POPULATION	METHOD 1 ERROR	METHOD 1 PER CENT ERROR	METHOD 2 ESTIMATED POPULATION	METHOD 2 ERROR	METHOD 2 PER CENT ERROR
27	3869	4523	654	16.9	3766	-103	-2.7
41	7649	10284	2639	34.5	9660	2015	26.4
42	8364	10894	2530	30.2	10451	2087	25.0
43	6456	7969	1513	23.4	7649	1193	18.5
44	4034	5282	1248	30.9	5144	1110	27.5
45	10272	11699	1427	13.9	11241	969	9.4
46	7341	8950	1609	21.9	8316	975	13.3
47	4209	5133	924	22.0	5091	882	21.0
48	2377	2898	521	21.9	2876	499	21.0
49	3870	4145	275	7.1	4087	217	5.6
50	1599	2092	493	30.8	2016	417	26.1
51	6410	6591	181	2.8	6677	267	4.2
52	3195	3398	203	6.4	3373	178	5.6
53	3589	3754	165	4.6	3788	199	5.5
54	3660	3642	-18	-.5	3648	-12	-.3
55	4432	4767	335	7.6	4767	335	7.6
56	4124	4651	509	12.3	4677	553	13.4
57	844	988	144	17.1	923	79	9.4
58	2109	2709	600	28.4	2393	284	13.5
59	1012	781	-231	-22.8	1129	117	11.6
60	820	1187	367	44.8	1028	208	25.4
61	8230	8912	682	8.3	8924	694	8.4
62	7408	7717	309	4.2	7573	165	2.2
63	9407	10737	1330	14.1	10795	1388	14.8
64	4579	4852	273	6.0	4830	251	5.5
65	3145	3802	657	20.9	3726	581	18.5
72	4587	5233	646	14.1	4693	106	2.3
			RMS=1018.41	$\bar{x}$=15.62		RMS=811.29	$\bar{x}$=12.54

*Source: San Bernardino Co. Special Census

TABLE 5.4.2

Estimated Population and Error for Selected San Bernardino Census Tracts

calculated 1975 housing acreages to produce a 1975 population estimate for each census tract. Two different density statistics were used as depicted in Figure 5.4.2. Table 5.4.1 contains data pertinent to the model. Estimates are contained in Table 5.4.2.

From the data it can be concluded that, for this experiment, population estimates are poor. This may be attributed to several causes. First, the assumption of little housing density change through time may be erroneous. However, no correlation could be found between per cent population change and per cent change in persons per occupied dwelling unit or persons per acre. Secondly, it was discovered that the grid cell approach tended to overestimate housing area. If the error is consistent in both years the impact is minimal. Another reason for poor performance, and the most compelling one, is that the 1970 and 1975 census counts were taken utilizing different enumeration methods. Therefore any estimating procedure based on change data may yield spurious results. Although the estimating procedure does not work, no reason can be found as to why it does not work.

Further redefinition of the experiment is being carried out in an attempt to control for data inconsistencies. If the reason for poor performance can be discovered, steps can be taken to improve accuracy. There is no evidence at this stage to suggest that the basic approach of utilizing remote sensing for population estimation would be fruitless.

5.5 Future Studies

5.5.1 Feasibility Study: Remote Sensing as an Aid to California Citrus Crop Forecasting

In 1976, the California-Arizona Valencia Orange crop forecast proved to be about 25% below actual production figures. Citrus industry experts estimate this error led to a six million dollar loss to the growers, packers, and processors. Representatives of the Orange Administrative Committee, operating under authority of the 19?7 Federal Marketing Order, have queried the Riverside campus researchers regarding the use of remote sensing techniques to improve their estimating capability. The estimators are certain that their poor record this past year is due in considerable part to inaccurate input data they receive.

Annual production forecasts are used by the Committee to prorate the flow of oranges to market during the entire season. Forecast data is obtained from that previous year's production, sample surveys of current crop, and packing house estimates. The previous years' records are established by each packing house reporting the number of field boxes received from each grower and the number of acres involved. The sample surveys are conducted by experts "eyeballing" the fruit on the tree and estimating the size and amount from previous experience. The total acreage in oranges in California-Arizona districts is approximately 91,058 hectares (225,000 acres), and because of time and cost constraints only a small sample can be taken. Another type of sample survey is performed by randomly selecting trees from each district and counting the actual number of fruits on the trees. The latter procedure leads to further complications. During the first few years of growth, the citrus tree is non-bearing. Ordinarily it reaches full production at 13 years of age. Production then declines to a point where the tree should be replaced about the twentieth year. The sample selection may not always account

for the difference in the age of the trees. It is apparent that many inaccuracies exist in the data from which citrus forecasts are made and will probably continue so long as subjective determinations of acreage and fruit size continue to be made.

Previous research has shown that low altitude imagery can provide accurate acreage data, and that the imagery need be flown only once every four or five years. To answer the initial question of what can remote sensing do for the citrus industry there is need for research to be done in some specific areas. The use of LANDSAT imagery to monitor the change in producing acres in the intervening years between low altitude flights should be studied and the accuracy of the data so obtained should be determined. The ability of remote sensing to ascertain the exact number of bearing and non-bearing trees in each block of citrus should be determined. The possibilities of developing remote sensing techniques to determine the age or maturity of the trees should be investigated. A more difficult, and perhaps the most crucial question, is whether or not remote sensing techniques can be developed to provide a faster, more accurate, and less expensive method of fruit-per-tree count as compared to the current manual tree sampling methods.

Representatives of the Orange Administrative Committee have indicated that they would consider providing matching funds for remote sensing research. Informal indications have also been received that the State Department of Agriculture has a strong interest in having the research accomplished. The Riverside Campus Group is in a unique position to conduct such research because: (1) we are co-located with the University of California Citrus Research Center, and (2) current research personnel on the NASA grant project hold joint appointments in the Agriculture Experiment Station. The expertise that has been established by the Research Center since its founding in 1907 is available to us through consultation with their personnel.

It would seem highly appropriate for a portion of the research conducted by the Riverside Campus Group next year to be directed toward a feasibility study to determine the usefulness and cost-effectiveness of remote sensing in aiding the citrus crop forecasting program. However, it is probably that, with the termination next year of our NASA grant in its present form, all or most of the support required by our group for this study would need to come from other sources.

It is proposed that a portion of the research conducted by the Riverside Campus Group next year be directed toward a feasibility study to determine the usefulness and cost-effectiveness of remote sensing in aiding the citrus crop forecasting program. If the research does prove successful it is likely that a procedural manual would be produced.

5.5.2 Automated Land Use Mapping Software Documentation

The documentation of programs for the automated land use mapping system (Section 5.2) should necessarily be included with the Procedural Manual. Computer programs presently used in the system are only partially documented. That is, an individual can use the programs without much supervision but only after considerable explanation and training.

It is proposed that all programs be thoroughly documented as to program structure and algorithm design as well as operational characteristics. Program listings will also be provided. A small amount of software development will be required to make the programs more general purpose than they now exist. It should be noted that the publication of these programs can in no way imply continued support or extensive assistance by personnel of our remote sensing group should a user decide to implement them.

5.5.3 Final Report on Water Demand Studies

Next year's grant work will complete our studies of the Water Demands in the Upper Santa Ana River Drainage Basin. In addition to the details of the final report it is anticipated that the two current projects (Irrigated Agriculture Detection, and Inter-census Population Estimates) will require some effort to bring them to completion.

CHAPTER 6

SOME SOCIOECONOMIC OBSERVATIONS ON REMOTE SENSING APPLICATIONS

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Chapter 6

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SOME SOCIOECONOMIC OBSERVATIONS ON REMOTE SENSING APPLICATION EFFORTS

6.0 INTRODUCTION

With the unique perspective of one who has shared their vantage point, former astronaut Russell Schweickart has described earth resource satellites as harvesters of the Earth's "information crop" of reflected radiance. "Our challenge," he remarked at NASA's Earth Resources Survey Symposium in June 1975, " is to learn to harvest and utilize this crop intelligently."[1] Most researchers associated with this Integrated Grant during the last six years probably would agree with Schweickart's statement. The challenge is particularly trenchant for those of us in the Social Sciences Group. From the vantage point of our social science orbit, we are able to observe aspects of the information harvesting and utilization process often invisible from technical perspectives.

Our observations have been reported regularly in these Progress Reports and other sources. Viewed in retrospect, they furnish insights into some of the growing pains and accomplishments within the childhood of satellite earth resources remote sensing applications. Viewed prospectively, the observations suggest how developing applications might be assisted toward maturity. A bidirectional viewpoint, reminiscent of Janus, the ancient Roman god of gates and beginnings with two opposite faces, is especially appropriate at this time, since many technical findings of the Integrated Grant will soon be summarized in procedural manual format. A social science document to complement the procedural manuals is under development, but we feel selected observations merit further exposure and consideration in this Progress Report. We have grouped our observations into six areas of concern.

6.1 Role of the Social Sciences Group

Throughout the last six years, the role of the Social Sciences Group vis-à-vis the Integrated Grant has remained remarkably consistent. A statement from our Progress Report of February 1971 reads: "The objective of the Social Sciences Group is to examine the needs for ERTS and related data on earth resources with respect to the management of resources and the ultimate benefit to the public." A parallel statement, prepared August 1976, sets forth the objective to "ascertain how remote sensing information can be used to enhance the framework in which resource managers make and implement decisions." Despite the language used, the two statements convey roughly the same meaning: the area of inquiry that concerns the Social Sciences Group is the interface between the technology and the society it has been designed to serve, i.e., between the technical and the user communities.

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[1] Russell L. Schweickart, "Future Remote-Sensing Programs," in Procedures of the NASA Earth Resources Survey Symposium, Volume II-A, Houston, Texas, June, 1975, p. 79.

Several more specific objectives are included in this overall focus. Primary among them is a commitment to perform realistic assessments of a new technology's developing applications. Our approach is practical and pragmatic; we harbor no presumptions about theoretical or methodological breakthroughs. Although we borrow from systems analysis techniques, cost-effectiveness measures, and other "tools of the trade" as appropriate, our emphasis is on the total spectrum and not isolated to just its quantifiable aspects. Much of the emphasis in technology assessment has been on the application of benefit-cost analysis to particular remote sensing applications. Our research in this area focuses on the adequacy of data, propriety of assumptions, and the ways intangibles are taken into account. We discuss further our observations on evaluation methodologies and technological assessment in a section below.

Water - identified long ago as one of the four intrinsic natural resources[2] - has been a focal point of our research in connection with the Integrated Grant. Consequently, many of our more specific objectives in some way concern remote sensing and water management. They include the following:

(1) To achieve a better understanding of the institutional dynamics and mechanisms through which water policy decisions are made and implemented. This involves reviewing the roles and responsibilities of the multiplicity of governmental bodies at all levels, from local to federal. This supercedes mere recourse to organization charts and statutes.

(2) To seek out and investigate potential users and uses of remote sensing. In various phases of water management, there is the assured likelihood that better, more accurate, more up-to-date information would improve decision-making processes. Yet the gaps between the potential user community and the technological capability available to them are evident. This objective aims to narrow these gaps.

(3) To establish and maintain rapport with persons responsible for the management of California's water resources. These working relationships help us determine with greater articulation the information requirements on which policy is based, decisions made, and operations designed.

(4) To delineate, observe, and assess the social forces bearing on decisions about water resource management. These include prevailing economic conditions, land use policies, attitudes about environmental protection, the credibility of information sources, growth policies, political posture on water resource matters, and methodologies for assessing impacts or for making long-range forecasts.

(5) To identify the factors, institutional, bureaucratic, historical, legal, and psychological, which influence receptivity among members of the water management community to new information sources.

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[2] The ancient Greeks divided the universe into four intrinsic natural resources - earth, water, fire, and air - from which all other materials could be derived. Sunlight (fire) is the principle energy source.

Many aspects of our ongoing work are carried out in tandem with the technical side of the Integrated Grant. Recent examples of this coordination have included various evaluations and cost-effectiveness studies on specific remote sensing applications performed by the Remote Sensing Research Program at the Berkeley campus. Work is also in progress concerning the water demand modeling decision framework under investigation by the Geography Remote Sensing Unit at the Santa Barbara campus.

The parallel nature of social and technical research in this project is seen most clearly by returning to the basic concept of four intrinsic natural resources. From various combinations of earth, water, fire, and air, a society can derive "raw materials" such as minerals, timber, agricultural products, and fish. These in turn can be transformed into "processed materials" like fuels, chemicals, food, and all the material amenities of modern society. It is obvious that this transformation does not occur automatically. Instead a canopy of social resources, consisting of institutions, capital, skills, and information, is necessary to turn natural resources into goods and commodities. Figure 1 illustrates the proposition.

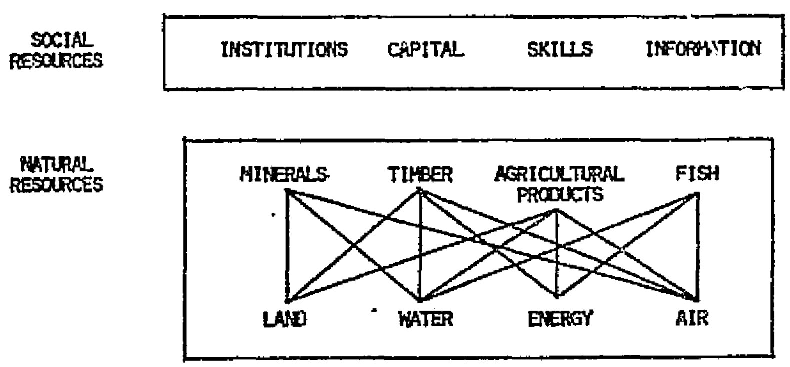

Figure 6.1: Canopy of "social resources", required to make natural resources useful.

Given this sort of framework, it should come as no surprise that the bulk of remote sensing application efforts, for social and technical researchers alike, concerns processes operating within the social resources canopy. We all deal mainly with the conceptual and informational spaces associated with natural resource or physical space phenomena. As part of the Integrated Grant, the activities of our Social Sciences Group can be summarized as being concerned with the relationships between remote sensing technology and the social resources canopy. Moreover, we are especially interested in the changes required (in institutions, capital, skills, and information) to facilitate the enhancement of existing resource management activities with the aid of remotely-sensed data.

6.2 Centrality of the User's Decision Processes

A detailed examination of Social Sciences Group objectives is hardly necessary to notice a particularly strong emphasis on the decision processes of the technology's intended beneficiary - the user. The emphasis is intentional. Improved decisions are the ultimate objective of nearly all remote sensing applications. Moreover, we find that decisions and decision processes provide the key link between an organization's natural and social inputs and its management actions and other outputs. These same processes also provide the key to assessing remote sensing impacts.

NASA and other offical sources are giving increasing recognition to the user's pivotal role in the remote sensing technology transfer process. The National Academy of Sciences, in their landmark CORSPERS report, describe the step needed for the technology's next phase of development: "To date, the program's thrust has been primarily motivated by technology development interests. Now it is time for user requirements to dominate the program."[3] Correspondingly, NASA's Landsat-related research has taken a definite turn toward emphasizing user-oriented applications verification testing as opposed to earlier trends involving research on the information itself. Charles W. Mathews, while Associate Administrator for Applications, described NASA's Applications Transfer and Demonstration Program in these words:[4]

> This program area constitutes our major effort to involve user organizations in applications of remote sensing so as to accelerate the adoption by the user community of those techniques which are valuable in carrying out their operational resources management missions. The great majority of these projects, known as Applications Systems Verifications Tests (ASVT), are relatively large scale cooperative endeavors that NASA enters into by written agreement with other Federal agencies and state governments, as well as with regional and private groups, to develop and demonstrate over a period of two or three years the operational utility of remotely sensed data to the solution of resource management problems.

As those involved with the user-oriented programs are rapidly discovering, unraveling the organizational dynamics of a user agency can be a more demanding task than reducing data from a satellite. Unlike technical operations, human organizations are full of unarticulated purposes, values, assumptions, and tradeoffs that frustrate reductionistic modeling efforts. Attempts to coordi-

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[3] National Academy of Sciences, Committee on Remote Sensing Programs for Earth Resource Surveys, Remote Sensing for Resource and Environmental Surveys: A Progress Review, Washington, D.C., 1974, p. 16.

[4] Charles W. Mathews, prepared testimony on 5 February 1976, in U.S. Senate Hearings, 94th Congress, 2nd Session, Committee on Aeronautical and Space Sciences, NASA Authorization for Fiscal Year 1977, Part 2, p. 1292.

nate programs between different organizations only add to these problems. The lesson is clear for the new wave of user-oriented researchers: avoid tendencies to oversimplify or to isolate decisions from their social context. William Stoney, NASA's Director of Earth Observations Programs, voiced concern on this matter at the 1975 Earth Resources Survey Symposium:[5] "The more we deal with the user community, the more we see the need for looking at the user's total job. What are the informational needs and how does the remote sensing information fit into that package?"

6.3 Conditions For Receptivity

Investigation of the user's decision processes leads naturally to a consideration of those circumstances that are likely to increase a user's receptivity to new technology. These are the sorts of intangibles generally omitted from benefit-cost ratios and feasibility studies. Yet they are often the primary determinants of a user's posture toward technology acceptance. So far, we have identified the following technology-related features that can influence a user's receptivity to applications involving remote sensing:

(1) Complexity. The pace of a user's learning or adoption of a new technology is governed by that technology's complexity. In other words, "If they don't understand it, they won't use it."

(2) Specificity. The technology application must specifically address the user's particular problems. An elaborate "mousetrap" is unlikely to be well-received in an organization with plenty of standard traps or no mice. Furthermore, new technologies must prove themselves along the way, and the "proof" must be fairly tangible and visible in relatively short time.

(3) Availability. Early response from Landsat users and researchers indicated that speed of availability was a more important consideration than NASA officials had planned on. Shortages of funds produced bottlenecks and criticism that NASA operated like a Soviet department store, where customers stand in interminable lines for their purchases.[6] Speed of data availability has since improved.

(4) Reliability. This concept has a dual meaning: one referring to the quality and consistency of data, the other to the continuation of the data source. The second meaning lies at the core of the Landsat data "chicken and egg" problem where users are reluctant to use the data unless they can be assured of its continued availability, and where federal support for additional Landsat-type satellites is contingent on demonstrated user acceptance.

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[5] William Stoney, "Remote Sensing and Applications," in Proceedings of the NASA Earth Resources Survey Symposium, Volume II-A, Houston, Texas, June 1975, p. 9.

[6] Gene Belinsky, "ERTS Puts the Whole Earth Under a Microscope," Fortune, February 1975, pp. 128-129.

(5) Accessibility. Here we refer not to the efficiency of the delivery system (availability) but to its openness of access. Prospective users invariably ask about the secrecy associated with the gathering and dissemination of Landsat-type data. They usually are relieved to find that unlike publicly-inaccessible military satellite data which require detailed personal security checks, obtaining data gathered by civilian satellites is no more difficult than ordering from mail-order catalogs. Freedom of access is axiomatic as a condition for receptivity.

(6) Compatibility. Potential users often are reluctant to try out new data sources if they are incompatible with familiar decision models. Compatability is particularly important when the user is attempting to blend multiple sources or uses of data.

Several categories of user-related characteristics also play an important role in determing receptivity. The first of these comes under the heading, bureaucratic, and the second, personal, the latter referring to attributes of those individuals in a position to make decisions about the introduction of new technologies. Most observers of organizational behavior agree that the first law of bureaucracy is to follow the path of least resistance. Hence, anything that threatens the status quo is likely to be met with overt or covert resistance. Bureaucratic recalcitrance in the face of change is commonplace, although the extent of it varies with the kind of innovation being introduced.

Resistance is especially marked when new technology entails a change in knowledge level, i.e., when it is accompanied by methods that require new skills, perhaps at a higher level than those previously needed. Where the new technology can perform more "efficiently", i.e., get the work done with fewer positions, the level of anxiety and amount of resistance are considerably heightened. Almost inevitably, fear of loss of control as new technology and new methods cause shifts in the division of labor constitutes a major barrier to smooth transition. Faced with the danger of being eliminated or becoming atrophied, divisions and departments struggle to survive by whatever means they can muster.

Technological innovation will not find a hospitable environment in the organization where the prevailing persuasion is that the agency already possesses the means to accomplish its mission. There must be a positive incentive to change, and usually a perceived need provides that impetus. When this perception is coupled with an understanding of the techniques associated with utilizing the data, the transfer process is considerably eased. Cognizant of these relationships between (1) need, (2) understanding of techniques, and (3) receptivity, the researchers associated with the Integrated Grant devote considerable

time and energy to what might be called "missionary work", i.e., sensitizing managers to their needs and acquainting them with the technical means through which they may be served. We find the climate for reception in large organizations is increased by working simultaneously with the organization's policy formation and application levels. Also, organizations are likely to be more responsive if given opportunities for trialability, i.e., being able to try the innovation out on a limited basis, and observability, i.e., being able to participate in the formulation of tests to evaluate the new technology.

6.4 Interrelatedness of Issues

Preoccupation with individual decision points in organizations runs the risk of obscuring the larger social landscape. In our ongoing research into California's water management industry, we attempt to map this landscape, highlighting both small and large concerns as they relate to technology assessment questions. Sifting out meaningful trends and relationships from inconsequential and transitory events is no simple task. Water policy decisions, as emphasized in earlier reports, are not simply the fruit of some well-pruned "decision tree". Instead, the water policy decision environment more closely resembles an unruly "bramble patch", thoroughly intertwined with networks of overlapping jurisdictions.

To map thoroughly the bureaucratic undergrowth surrounding California's water management community is a virtually impossible task. For one reason, the water management environment is too extensive: boundaries and generalizations must be created to reduce the task to manageable proportions. For another reason, the environment is too dynamic: even if a complete picture could be developed, it would soon be outdated. The best we can hope to do is roughly scan this territory taking note of significant relationships and apparent trends.

Continuing with the analogy, we can imagine that the length and breadth of our conceptual bramble represent water, water-related resources (such as land, energy, and air), and their uses. Within the patch's depth are concealed the various of public and private organizations that manage or exploit the basic resources. That portion of the patch growing from the water resource stem is particularly gnarled and overgrown. Long tendrils representing the traditional "economic" water uses (irrigation, industrial and domestic supplies, etc.) intermingle with in-stream and conjunctive uses. Young, rapidly-growing shoots representing water quality and water conservation concerns seem to appear almost everywhere. Water-related resources -- energy and land especially -- intertwine with the extensive water brambles. Among the inhabitants of this tangle are our familiar water management agencies: the Department of Water Resources, State Water Resources Control Board, the U.S. Army Corps of Engineers, Bureau of Reclamation, regional and local water agencies, etc. Other resource management agencies also live there; the U.S. Environmental Protection Agency, Bureau of Outdoor Recreation, Department of Agriculture, Department of Interior, Energy Research and Development Administration, the State Department of Fish and Game, Department of Food and Agriculture, and the new Energy Resources Conservation and Development Commission, and many more.

Obviously, biological analogies have their limits when used to describe socioeconomic processes. An important limitation is that of developmental predictability. The life cycles of most common biological networks are generally well understood and predictable. This is not so in human society. We have no established methodology for confidently predicting future changes in the "sociopolitical climate", much less how they might affect resource bramble patches and their inhabitants. Continually changing climate conditions encourage the bramble to grow, develop, or decay in certain ways. It is difficult enough to agree on the effects of past social changes or whether there have been any major changes at all! Once again, interpretation difficulties are the result of the social landscape's enormous extent and the huge volume of simultaneous and often conflicting events.

Figure 2 illustrates a conceptual tool for analyzing the intertwined brambles that thrive in the decision space surrounding resource management issues. Borrowing from NASA terminology, the concept can be likened to Landsat's multi-spectral scanner. Resource issues appear as signatures on four perceptual "bands" that break incoming information into physical-environmental, economic, social, or political categories. Although not composed of photoelectric cells, the sensors are calibrated to questions that help identify the issues involved.

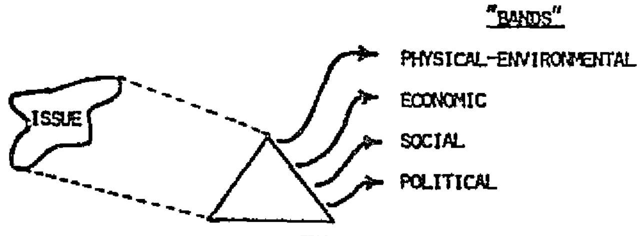

Figure 6.2: A "multispectral" view can help untangle the brambles surrounding resource management issues.

The <u>physical-environmental</u> band registers information that pertains to questions concerning those phenomena commonly associated with the natural sciences.-- normally with properties measurable in physical, chemical, or biological terms. Questions concerning the measurement and prediction of impacts, in fact, lie at the core of the physical component of most issues. The typically long time horizon of environmental concerns further complicates measurement difficulties. What are the cumulative adverse effects on soil, water, mineral or other resources given particular agricultural practices? What level of pesticide toxicity is safe to use around livestock? How much soil salinity can various crops tolerate? What is the likelihood that this year will be as dry as last year? How rapidly will ground water mining deplete an area's natural subsurface water supply? Questions relating to environmental impact measurements typically raise new questions concerning the boundaries of those impacts. Federal and state water development projects in California, with interlocking storage, pumping, and conveyance facilities stretched over hundreds of miles, have particularly far-reaching effects.

Most signals in the physical-environmental band generate a comparable set of economic questions. The most obvious consequence in the economic band of a physical problem like excessive groundwater pumping, for example, is a dramatic increase in drilling costs. The questions asked here concern values, prices, and who benefits or pays the costs. Again, time horizon considerations can be particularly troublesome. Agricultural practices, highly profitable in the short run, may have disastrous long-run consequences and lead to an accelerated degradation of resources. The problem lies in the assumptions used to determine values. Often these are based on market prices that fail to capture the full social costs of production. This is not to imply that non-market costs are easily evaluated; usually they are not, especially since most incorporate measurement uncertainties originating in the physical realm. Even when prices are known, they warrant close scrutiny. Subsidies pervade all resource industries, and prices respond accordingly. Also, controversies over relative prices are intermixed with controversies over relative "efficiencies". Debates over economic efficiency are of little meaning unless space and time coordinates are specified: efficient for whom?; using what costs?; over what time horizon?

A variety of laws, subsidies, tax policies, and other intangible arrangements provide linkages between topics in the social realm and those in the physical and economic realms. Unlike measurement and valuation inquiries, questions concerning the social aspects of issues are often normative. What social goals deserve encouragement? By what criteria and weights should these goals be ranked? How should the resulting priorities be implemented? Like physical measurements and economic evaluations, social goals are strongly influenced by the time dimension. In all three realms time introduces uncertainty and ambiguity into the interpretative process. In the social realm, however, time acts more like an invisible cook, constantly stirring, diluting, and augmenting a large potage of social goals. The National Reclamation Act of 1902, for example, combined equity considerations (land reform and social justice) with those of efficiency (agricultural production). In the 1970's, these Nineteenth Century ideals have been resurrected and introduced into a debate on agrarian "lifestyle". These issues are reinforced by the emergence of additional social objectives concerning public involvement and environmental preservation.

Events in the political band determine much of what occurs in an issue's physical, economic, or social manifestations. It is here that many questions concerning measurement, evaluation, or goal selection are integrated, debated, restated and, occasionally, resolved. The principle questions asked in the political realm is: Who decides? Who decides who should benefit, or pay, or administer a particular program? Like social questions, political questions are fundamentally normative and are undergoing continual change or redefinition. Much can be learned about the political elements in interrelated issues by examining those areas where the interests of different agencies coincide, and whether conflict or cooperation results. The dilemma of interagency con-

flict was addressed in a recent lecture by Assemblyman Charles Warren, Chairman of the California Assembly Committee on Resources, Land Use, and Energy:[7]

> What we are finding is that government both here and in Washington is trapped in an organizational and policy paradox that was created largely during the boom times of the 1950's and patched up in the 1970's. We have one agency battling to mitigate the consequences of actions taken by another agency frequently under the nose of the same cabinet secretary.
>
> This is not a rare occurence.
>
> Agencies are internally hemorrhaging from the increasing strain between promoting growth, controlling its adverse effects, and facing resource scarcity.

6.5 Emerging Trends

Biological analogies and four-level paradigms are two ways of understanding the resource issues found within the social landscape. Identification of emerging trends is another. Water management in California, like many other resource management activities, is being profoundly influenced by major changes taking place in the larger social environment. As Assemblyman Warren observed, the growth orientation fashionable in the 1940's and 1950's appears to be undergoing modification as the result of new perceptions developed in the 1960's and 1970's. We have identified in earlier reports at least three such major changes:

(1) An awareness of new publics

(2) An awareness of negative environmental side effects

(3) An awareness of resource constraints

These three streams of awareness appear to be converging on a global and national scale. The first two have already generated a mountain of federal and state legislation concerning social justice and environmental protection. The third major change is only now beginning to affect resource management organizations, public and private, at local, national, and international levels. Water management activities in California, fostered by a favorable climate of

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7 Assemblyman Charles Warren, "Critical Resources Issues in 1976: The State of the State," Lecture sponsored by the Earl Warren Legal Institute, Institute of Governmental Studies, and Committee on Arts and Lectures, University of California, Berkeley, 22 January 1976.

candor in Sacramento, reflect many elements of this convergence. At least three manifestations of the phenomenon can be identified:

(1) A changing emphasis from resource development to resource management.

(2) An increasing emphasis on comprehensiveness in water resources planning, including:
   (a) An attempt to relate to other functional areas;
   (b) An attempt to integrate more effectively with other jurisdictional areas;
   (c) An attempt to increase meaningful public participation.

(3) A growing appreciation of the need for anticipating and assessing the environmental effects of new projects, programs, and policies, coupled with a growing awareness of the inherent limitations of environmental assessment studies.

The first observation has significant implications for an information-rich technology like remote sensing. Although both development and management functions require information regarding costs, environmental impacts, and so forth, the management function, in particular, requires continuous and periodic information for monitoring the performance of a resource management system. Accurate and timely monitoring becomes all the more important when one is trying to stretch a given resource over more users (e.g., water conservation), or to measure negative side effects of stretching that resource too far (e.g., pollution, salt water intrusion, subsidence).

Both the second and third observations reflect apparent trends toward greater comprehensiveness in public planning processes. Growing appreciation of the "bramble-like" qualities of resource management issues has prompted California's Department of Water Resources, among other agencies, to acknowledge a need for greater functional and jurisdictional integration within its planning activities. The result has been increased DWR consideration of land use, energy, and demographic issues as well as greater coordination with the policies of agencies like the State Water Resources Control Board, the State Department of Agriculture, the U.S. Bureau of Reclamation, and the Army Corps of Engineers. For remote sensing, this pattern of development means more applications of the technology are likely to involve multiple users, uses, and sources of data. Similarly, greater emphasis on public participation and environmental assessment implies that remote sensing is likely to be involved increasingly both as (1) a display medium, and (2) in conjunction with specific resource management plans and assessments that directly utilize remotely-sensed information.

6.6 Technology Assessment and Evaluation Methodology

Planning processes of all types traditionally concern themselves with the consequences of alternative decisions. Only recently, however, has preoccupation with environmental impacts become an integral part of most plans that affect the public domain. Environmental quality legislation, notably the National Environmental Protection Act of 1969 (NEPA), the California Environmental Quality Act of 1970 (CEQA), and subsequent interpretations, is responsible for stimulating much of the environmental assessment carried on in California. Continued evolution of this trend in the direction of greater comprehensiveness seems probable. Environmental impact statements, in other words, are likely to expand to resemble more closely the idealized form of technology assessments.

Technology assessment methodology itself has undergone considerable change and controversy as it has evolved over the last decade. Our earlier reports describe technology assessment as an amalgam of techniques derived mainly from operations research and systems analysis and, therefore, basking in a borrowed glory because of their prestigious heritage in defense and space management. Most of the discipline's applications have centered on narrowly-construed problems in military, public works, or business domains. All too often weighty conclusions are supported on a fragile base of deceptively precise benefit-cost calculations. The failure of such studies to inquire about wider social costs and benefits <u>and their incidence</u> on various publics sometimes leads to unfortunate effects, including popular backlashes against engineers, scientists, and public officials.

Experience with the earlier generation of technology assessment efforts has prompted a reconsideration of their role. A more mature approach appears to be emerging. For one thing, there is a growing concensus on what a comprehensive technology assessment should be. François Hetman's <u>Society and the Assessment of Technology</u>[8] gives us several clues:

(1) Any assessment implies a comparison of advantages and disadvantages of a specific project or technology.

(2) A technology assessment consists of two complementary and closely interweaving processes: <u>forecasting</u> and <u>evaluation</u>.

(3) The object of a technology assessment is to distinguish between a technology's desirable impacts, undesirable impacts, and uncertainties.

[8] François Hetman, <u>Society and the Assessment of Technology</u>, OECD Publications, Paris, 1973, pp. 350-390.

(4) A comprehensive technology assessment attempts to consider all relevant aspects of a technology's impacts on society. It includes first-, second-, and third-order impacts as well as impacts on various constituencies.

(5) Technology assessment is a multidisciplinary approach; it is iterative; and it is an instrument of policy making.

For another thing, there is increasing sophistication concerning the limitations of the assessment methodology. Technology assessment and its chief evaluative underpinnings (cost-benefit and cost-effectiveness analysis) share several of these characteristics:

(1) They are social advisory activities and do not by themselves produce policy decisions.

(2) They are filled with value judgements and assumptions.

(3) They cannot be routinized.

(4) They depend on a continuous evaluation of the state of society, since rapid changes in socioeconomic conditions can upset many of their underlying assumptions.

Appreciation of the inherent limits of quantitative analysis underlies much of this change in attitude:

> Unhappy clashes with aroused groups of ecologists have proved that when a dam is being proposed, kingfishers may have as much political clout as kilowatts. How do you apply cost-benefit analysis to kingfishers?... In the long run the entire Cartesian assumption (that there are measurable and incommensurable quantities) must be abandoned for recognition that quantity is only one of the qualities and that all decisions, including the quantitative, are inherently qualitative.[9]

Also there is a realization that search for a single method for carrying out assessments has been misguided:

> The broad category of systems analysis is likely to be the central theme in any assessment. But there is no general method, methodology, or techniques yet developed for conducting a technology assessment.[10]

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[9] Lynn White, Jr., "Technology Assessment from the Stance of a Medieval Historian", Technological Forecasting and Social Change, 6, (1974), p.360.

[10] M.J. Cetron and B. Bartocha (eds.), Technology Assessment in a Dynamic Environment, Gordon and Breach, New York, 1973, p. 285.

If nothing else, continuing maturation of the technological assessment approach has produced a new humility regarding the interaction of technology and the complex systems that encompass man, society, and the environment. Increasingly, technological assessment is viewed as a means of obtaining some insights about the application of technology to some elements of such systems. Comprehensiveness is impossible; routinized approaches to different problems are unrealistic. A well-conceived technological assessment may overcome the obvious limitations of a narrowly-defined impact study or an overly-precise benefit-cost analysis, but it too will have limitations. Nonetheless, an improved understanding of various technologies and their effect on complex systems is necessary to avoid in the future many of the problems and mistakes of the past. A redefinition of the role of assessment techniques can be a great help. Technology assessment cannot occur in a vacuum: it is a process requiring simultaneous scrutiny of the technology, the surrounding society, and the assessment methodology itself.

NASA officials acknowledge that technology assessment is critical to the success of their earth resources survey program. Russell Schweickart has described adequate assessment as one of the "strong prerequisites" of an operational remote sensing capability:[11]

> Mainly, we will have to convince the decisionmakers and the user community of the economic effectiveness of this capability to do necessary jobs here on Earth. Without hard and rigorous effort along those lines, we will not get there from here ... I think that, as we pursue the operational or quasi-operational applications of these data, we are going to have to pay as much attention to this aspect of the program as we do the area of technical performance.

The question facing NASA and the user community, however, is not whether there should be assessments but what form they should take. A recent report by the General Accounting Office highlights the vastly different results from two major assessments of the benefits and costs to the United States of an operational space-based earth resources program. One study, funded by NASA estimated a 12:1 benefit/cost ratio could be achieved for an operational system over 16 1/2 years; the other study, funded by the Department of Interior, estimated a ratio ranging from 1.9:1 to 0.4:1 for a 10 year period. Varying assumptions and differing data used in the studies "had a large and direct influence on the widely divergent benefit/cost ratios reported," the GAO report concluded.[12]

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[11] Schweickart, op. cit., p. 82.

[12] U.S. General Accounting Office, Land Satellite Project, PSAD-76-74, 30 January 1976, p.33.

In addition to their dubious conclusions and obvious vulnerability to changed assumptions, these voluminous but vacuous assessments present another difficulty: they do little to enhance technology utilization. Most potential users of remote sensing technology are simply unmoved by paper-and-pencil games. They recognize that official benefit/cost ratios exclude many considerations important to them. They see impacts on their own decision processes, job security, and organizational behavior being overlooked while spurious correlation coefficients and contrived calculations are being overworked. The result for the technology developers is an evaluative "boomerang effect" in which users perform their own subjective evaluations and conclude, for various reasons[13], that fruits from the new technology are not worth their price.

By contrast, our conception of technology assessment is pragmatic; we prefer to deal with the real live actors and to observe them as they cope with the real life problems of resource management. Just as NASA's technical research emphasis is now shifting from technical performance studies toward applications verification testing, so we feel it is appropriate that socioeconomic research concern itself less with quantifying the value of new information and more with the means for achieving technological utilization.

Our notion of a worthwhile exercise in technology assessment is to observe where and how technically-derived information can impinge on decisions and improve the processes in some way.[14] Only thus can we break away from the ersatz and contrived simulation and judge technology for what it is really worth. And for this purpose, the ongoing effort of the Integrated Grant, with its broad array of talents and wide representation from a number of pertinent disciplines - all concentrating on California water resources - represents an ideal vehicle.

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13 See above section on "Conditions for Receptivity".

14 As detailed in many of our previous progress reports, the making of such observations constitutes a major portion of the activity of our Social Sciences Group.

CHAPTER 7

SPECIAL STUDIES

SPECIAL STUDY NO. 1

REPORT ON THE UNITED NATIONS/IAF WORKSHOP ON REMOTE SENSING (ANAHEIM, CALIFORNIA, 27 SEPTEMBER - 8 OCTOBER, 1976)

Conducted by participants in the present NASA Grant:

Robert N. Colwell and Sharon Wali, Workshop Coordinators

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I. INTRODUCTION

A. Background and purpose of the seminar

1. This seminar was part of the program for 1976, as recommended by the Scientific and Technical Sub-Committee of the United Nations Committee on the Peaceful Uses of Outer Space at its twelfth session and endorsed by the United Nations General Assembly.

2. The seminar was jointly sponsored and organized by the United Nations and the International Astronautical Federation (IAF), in co-operation with the American Institute of Aeronautics and Astronautics (AIAA).

3. The purpose of the seminar was to train participants from developing countries in the use of remote sensing for earth resources and environemntal survey.

B. Organization of the seminar

4. The seminar was held in Anaheim, California, USA, from 27 September to 16 October 1976. The IAF and AIAA were responsible for all local arrangements and the preparations and implementation of the programme. Invitations to nominate participants for the seminar were extended by the United Nations to all developing nations.

5. The seminar was attended by 30 participants from 20 countries: Argentina, Bangladesh, Ecuador, Ghana (3), India (3), Indonesia, Iran (2), Iraq, Israel (2), Liberia, Mexico (2), Malaysia, Nepal (2), Papua New Guinea, Peru, Romania, Senegal (2), Thailand (2), Turkey and Uganda. The participants were qualified scientists with professional experience and duties in one or more of the disciplines covered by the programme.

6. Funds allocated by the United Nations under the United Nations programme on space applications were used to meet subsistence and incidental expenses during the workshop. IAF arranged for the funds to cover the cost of instructional materials and other requirement for the conduct of the seminar.

7. At the closing session of the seminar, the participants had the opportunity to express their views, comments and recommendations on organization of this seminar as contained in section III of this report. Mr. L. Jaffe, President of the IAF, Mr. L. Perek, Chief of the Outer Space Affairs Division of the United Nations and Mr. H. G. S. Murthy, United Nations Expert on Space Applications, were present at the session and expressed their views. Mr. Murthy outlined the United Nations space applications programme for 1977 and 1978.

II. SUMMARY OF THE PROCEEDINGS

A. Introduction

1. "Space and the developing nations": an introductory slide presentation

8. In two respects this presentation constituted an ideal introduction to the two weeks' remote sensing workshop: (a) it stressed, with the aid of examples, the value to developing nations of space-acquired remote sensing data relative to their natural resources, and (b) it indicated the already highly favourable working relationships that exist between the two joint sponsors of the present workshop in that the presentation was prepared for the United Nations by the International Astronautical Federation with the assistance of the American Institute of Aeronautics and Astronautics.

2. Some basic considerations in remote sensing of natural resources

(a) Terminology as applied to remote sensing

9. It was emphasized that a measure of the newness and also of the rapidity of growth of a science such as remote sensing is to be found in the preoccupation of that science with matters of terminology. As indicated by the following summary table, several terms that were used before the advent of remote sensing, and for the most part were already understood by the workshop delegates, were related to the newer and broader terms required by the advent of remote sensing.

Old term	Corresponding but broader new term
1. Photographic reconnaissance	1. Remote sensing
2. Photography	2. Imagery
3. Photographic interpreter	3. Image analyst

9a. A few additional terms, such as "computer assisted analysis", and "spectral response pattern" also were introduced but a rigorous defining of such terms was deferred until appropriate times later in the workshop.

(b) User requirements for information obtainable by remote sensing

10. First it was emphasized that the primary users of remote sensing-derived information are those concerned with the inventory and management of such natural resources as timber, forage, soils, water, minerals, agricultural crops, livestock, fish, wildlife, and recreational resources. Viewed in this light consideration was given to (1) specific types of information needed by each resource manager,

(2) the accuracy with which the information is needed, (3) the speed with which the information must be obtained, once the remote sensing has been accomplished, and (4) the frequency with which the information-gathering cycle needs to be repeated in order that the resource in question can be adequately monitored. As with each of the other portions of this material comprising an introduction to the course, frequent reference was made to the correspondingly titled section in the basic syllabus (reference 5 of the annex) which had been prepared in advance, specifically for use in this workshop.

(c) Types and uses of remote sensing devices

11. Among the devices considered were (1) the conventional aerial camera, (2) the high resolution panoramic camera, (3) various multiband camera systems, especially those used by the Apollo 9 astronauts, the Skylab astronauts, and on U-2 flights, (4) line scanners, including those operating in the thermal infrared region and the multispectral scanner used by the various earth resources technology satellites (formerly called ERTS and now known as Landsat), (5) side-looking airborne radar (SLAR) devices, (6) return beam vidicon devices, and (7) gamma ray spectrometers. In each case explanation was given as to the purpose of the device, its manner of construction, its mode of operation, and the spatial and spectral resolution offered by it. In addition, and in view of the foregoing, the primary uses of each of these devices were indicated.

(d) Characteristics and potential usefulness of various photographic films

12. First, consideration was given to various black-and-white films, including both conventional panchromatic films and those capable of providing black-and-white infrared photography. Then color films, both positive and negative, that are sensitized only for visible wavelengths of electromagnetic energy were considered after which such "false color" films as Infrared Ektachrome and a 2-color "Spectrozonal" film were described. In each case, the potential usefulness, and also the limitations of the film were highlighted, and reference was made to the corresponding section in the basic syllabus (annex 13) where detailed information regarding the film could be found.

(e) Information derivable from various levels of spatial, spectral and temporal resolution

13. Each of the three attributes (spatial, spectral and temporal) was first considered in isolation. Thereafter various combinations of these attributes were considered with emphasis being placed, in each example, on the extent to which information could be derived that would be useful to those charged with the management of natural resources in developing countries.

(f) Fundamentals of photographic interpretation, including the "multi" concept as applied to remote sensing

14. Advantage was taken of the opportunity provided by this section to integrate, in a very meaningful context, the concepts that had been presented in the preceding sections. Among the aspects emphasized were (1) viewing techniques and equipment, (2) techniques and equipment for measuring and plotting from remote sensing imagery, (3) the principle of "convergence of evidence" as applied to the identification of features and to the judging of their condition and significance, (4) the value of the "conference system" and of "multidisciplinary analysis" in deriving the maximum amount of useful information from remote sensing data, (5) the uses, respectively, of multiband, multidate, multistage, multistation, and multipolarization imagery, (6) the advantages and limitations of making multiple enhancements of such imagery by various optical and electronic means, and (7) the necessity of making multithematic presentations of the derived information. Frequent reference was made to the illustrations of these principles and concepts appearing in chapter I (Introduction to remote sensing) of the recently-published "Manual of remote sensing" of the American Society of Photogrammetry. A copy of that chapter, in full-colour reprint form, had been issued to each participant (reference 11 of the appendix) at the beginning of the workshop. Throughout the course, as various workshop-type exercises were being performed by the students, they were referred back to the principles and concepts discussed in this section.

B. Methodology, techniques and procedures of analysing remote sensing data

1. Procedures for determining the usefulness of any given type of photography for natural resource inventory

15. At the outset it was emphasized that the amount of useful information derivable by remote sensing depends upon (a) factors governing the quality of the data, including tone or colour contrast, sharpness, parallax, and the consequent spatial and spectral resolution, and (b) factors governing the analysis of the data (including the human factors of visual acuity, background of training and experience, judgment and motivation) as well as the methodology, techniques and procedures dealt with primarily in the present section. After various examples had been dealt with in workshop fashion, presentation was made of the most effective means for making quantitative tabular summaries of such photo interpretation results as "percent of features correctly identified," "percent of omission errors, by type," and "percent of commission errors, by type". As with the various other topics appearing in this section, frequent reference was made to the basic compendium of information comprising the syllabus for this course (reference 13 of the appendix).

2. <u>Principles and uses of stereoscopy, optical image enhancement and electronic imagery enhancement</u>

16. It was recognized that many students already had acquired, prior to their attending this course, the ability to view overlapping photographs stereoscopically and to produce and interpret various optical and electronic image enhancements. Therefore the presentation of these topics that was given to the entire group occupied only 30 minutes of class time. After the class had been adjourned for the day special instruction was given, in workshop fashion, to those who had had little or no prior experience with these basic techniques. Since this special instruction was offered in increments, beginning on the first evening of the two-week workshop, it is believed that all students had the necessary skills in these basic techniques before the more formal, discipline-oriented workshop exercises were undertaken.

3. <u>Computer processing methods in remote sensing</u>

(a) <u>The fundamentals and potentials</u>

17. Emphasis was placed at this point on (1) the importance of basing computer assisted analyses on multispectral tone or scene brightness values, since these are readily and consistently quantifiable whereas image texture, shape, site, association, etc. are not; (2) the various "decision rule" criteria that are used, including those based on the concepts of nearest neighbour, mean square distance, probability of occurrence, and spectral response ratios.

(b) <u>Workshop exercises in computer assisted analysis of natural resources</u>

18. Although computer equipment was not available for use by the individual workshop attendees, the sample problems given were scaled down to a size where the human could replace the machine and derive essentially the same answer as might have been obtained through computer analysis. It is believed that, as a result, the delegates appreciated quite fully the principles, uses and limitations of automatic data processing techniques.

4. <u>The construction of "shade prints" from linescan data</u>

19. As used in the present context, a "shade print" is a map-like sheet of paper produced in the form of a computer print-out of Landsat MSS data. Features on the surface of the earth (as digitally recorded by Landsat in terms of their brightness values) appear in different shades of grey on the computer print-out sheets for the following reasons: In the various alphanumeric symbols used in making the the print-out, each symbol representing a given type of earth resource feature, uses a different amount of ink. Thus, for example, more ink is used in printing the symbol "M" than in printing the symbol "C". The greater the amount of ink used in the print-out symbol, the darker the shade of grey which the

corresponding resource feature exhibits on the shade print. Consequently, when viewed at a distance, the shade print reveals the location and areal extent of each type of resource feature.

20. If as many as 10 to 30 different types of resource features are to be portrayed on the computer print-out sheet, a combination of colour coding and shade coding commonly is employed. This is done by means of multiple runs of the Landsat data through the computer print-out machine. Thus, for example, in the first run, resource types 1 through 5 may be "shade printed" in red, while all portions of the sheet containing the other resource types remain unprinted. The same sheet of paper may then be run through the computer a second time, after the print-out ink colour has been changed. During the second run, resource types 6 through 10 might be "shade printed" in green, etc. Examples of the use of these techniques and procedures were demonstrated and the relative usefulness of each was stressed.

5. The interpretation of photos taken from manned spacecraft

21. Some highly informative space photos of various parts of the globe have been taken during the past decade by astronauts on the various Gemini, Apollo and Skylab missions. A series of these photos, so selected as to illustrate portions of the countries represented by the present workshop's participants were projected on the screen and interpreted under the direction of Mr. Richard Underwood, Director of the Photographic Laboratory at the NASA Johnson Space Center in Houston, Texas. Since most of these photos are of higher spatial resolution than those obtained by Landsat, it was possible to determine the extent to which such increased resolution served to improve the ease and accuracy with which various types of earth resource features could be identified and delineated.

6. The "integrated information" approach to resource analysis

22. The key to this approach is multistage sampling. In a typical instance resource features throughout the entire area of interest are first stratified (i.e. delineated as to type) on Landsat imagery. With the aid of this stratification a form of probability sampling is employed in selecting portions of the area for which aerial photography will be flown in order to obtain more detailed information about earth resource features within the sampled areas. Usually the selection of these sample areas is done in such a way that the probability that a sample will be drawn from any given stratum is in proportion to the relative concentration within that stratum of the resource features that are of primary interest (timber, forage, etc.). In a third stage, the same probability procedures are used in selecting subsamples from within the sample areas that have been aerially photographed. The subsample areas are then visited on the ground, and highly detailed and accurate observations and measurements of them are made. Then, through the use of an equation known as the "multistage estimator", data regarding, e.g., the volume of timber or forage, as collected from the ground sample plots can be expanded to be made applicable to the sample areas that have been aerially photographed. These, in turn, can be expanded, stratum-by-stratum, to apply to the entire project area.

23. Examples were given of ways in which such ancillary data as historical records and meteorological satellite data applicable to the project area also can be included in this "integrated information" approach to the inventory of earth resources.

C. Applications of remote sensing to specific disciplines

1. Oceanography

24. Generally speaking, the oceanographic resources that are of interest to man stem from the ocean's plant life, known as "phytoplankton". Thus, in a typical instance, 1,000 units of phytoplankton will produce 100 units of zooplankton. This will, in turn, produce 10 units of fish, which can be defined as the amount of fish required to sustain the needs of one man. From the foregoing it is seen that an ability to map the ocean's phytoplankton is the key to our being able to map the ocean's productivity, area by area. The concentrations of phytoplankton in the ocean tend to shift from one place to another, however, much like the diurnal shifting of clouds in the sky. Nevertheless, just as some parts of the sky tend to be cloudier than others, so some parts of the ocean tend to contain more phytoplankton than others.

25. In view of the foregoing it is apparent that the key to mapping the productivity of the ocean, area-by-area, is to map its phytoplankton concentration, area-by-area, and at suitably frequent intervals. In the last analysis it is the number of milligrams of carbon per square meter per day, as fixed by phytoplankton through the process of photosynthesis, that constitutes the best measure of productivity. Since this photosynthetic process can only occur in the presence of a catalyst known as "chlorophyll a", efforts are being made to use remote sensing to map the concentration of "chlorophyll a" throughout the earth's oceans area-by-area and at suitably frequent intervals. In these efforts, which already have proved to be moderately successful, use has been made of the unique spectral signature of "chlorophyll a" based on the fact that it preferentially absorbs blue and red wavelengths of energy for use in the photosynthetic process while at the same time preferentially reflecting the green wavelengths.

2. Geology, geomorphology and pedology

26. The geologic structure and associated chemical nature of the earth's crust not only define its geomorphology but also the physical and chemical characteristics of the soils that are derived from these geologic "parent materials". Numerous Landsat images and aerial photographs were shown, and interpreted in terms of geology, geomorphology and pedology, area by area. Emphasis was placed on the use of such analyses in the location of important mineral and fossil fuel deposits. Thereafter, two very sizable workshop exercises were given to the students, each requiring the production of multiple overlays for the study area. The overlays portrayed, respectively, such geology-related attributes of the landscape as faults, lineaments, drainage pattern, slope, aspect and topographic texture. After each workshop problem had been completed, the results obtained by the students were compared with "ground truth" as provided by the instructor.

3. Hydrology

27. Emphasis in this phase of the instruction was placed on the use of remote sensing as an aid in the location of (a) developable aquifers, (b) suitable sites for impounding water, (c) suitable routes for the transport of water (d) determining the moisture content of soil and vegetation, and (e) determining the areal extent, water content, and run-off of snow fields. As in the geology-related exercises, the basic presentations in hydrology were followed by workshop problems in which the students attempted to interpret the above-listed hydrologic attributes from Landsat imagery and associated aerial photographs. Immediately thereafter they were provided with the correct solution to these interpretation problems, based on detailed field-checking and associated "ground truth".

28. In a concluding phase of this hydrology-related work, detailed consideration was given to the extent to which remote-sensing derived information could be used in various hydrologic models designed to quantify estimates as to (a) the supply of water, and (b) the demand for water, area by area.

4. Agriculture and related land use

29. At the outset it was emphasized that the following six types of information are the ones commonly desired with respect to agricultural crops: (a) the type of crop that is growing in each field, (b) the vigour or degree of health of each such crop, (c) the nature and identity of crop-damaging agents wherever they may occur (e.g., various insects, diseases, mineral deficiencies, mineral toxicities, problems of drought, drainage problems associated with perched water tables, etc.), (d) the probable yield that can be expected, per unit area, in each field, (e) the total area within each field and within each crop condition class, and (f) the total yield anticipated from each field and from each agricultural basin, by crop type.

30. Workshop-type problems were performed by the students based on the NASA-funded remote sensing project known as LACIE (large area crop inventory experiment). While the results achieved were generally successful, it became apparent that the best success in work of this kind could be expected from those having the greatest background of training and experience in the production of agricultural crops, especially within an area analogous to the one being interpreted and assessed from remote sensing data.

31. Although livestock also comprise an important part of the agricultural economy of most developing countries, treatment of this phase of agriculture was deferred so that it might be included under the subsequent topic of "range resources".

5. Forest resources

32. The primary objective of a forest resource inventory is to provide information, area by area, as to the volume of timber that is present, by species, size class and timber stand condition class.

33. A simple workshop-type exercise was first undertaken relative to the classification of forest lands on conventional aerial photographs taken with panchromatic film and a "minus blue" filter at a scale of 1/20,000. In this exercise 4 size classes and 5 density classes were recognized. It was emphasized that the use of this technique in California's 16 million acres of timber land resulted in a reduction in the amount of costly, time-consuming field work by more than a thousand-fold.

34. A second remote sensing-based system for classifying timber lands was then considered in detail, based on a multistage, multiphase procedure that employs space photography, two scales of aerial photography, and the highly precise measurement of trees on small subsample plots. The demonstrated benefits and limitations of this procedure were discussed in detail.

6. Range resources

35. A primary objective of a range resource survey is to determine the animal-carrying capacity of each portion of the range in terms of various kinds of domestic livestock (cattle, sheep, goats, etc.). This, in turn, poses the requirement for making both an inventory and a detailed in-place delineation of forage types by volume, condition and, where possible, by nutritive value to livestock. Particularly with reference to annual plants encountered on the range (including most grasses and herbaceous plants) the range manager needs information relative to "range readiness" so that he will know when is the optimum time to permit livestock grazing, area by area.

36. In addition, a range resource inventory usually seeks to determine the distribution of potable water, the presence and location of stock-poisoning plants, and the location of sites wherein various range rehabilitation measures need to be taken because of damage that has been done by fire, insects, diseases or accelerated erosion.

37. Based on work done for the US Bureau of Land Management, the various means that have been developed for maximizing the usefulness of multiband, multidate and multistage remote sensing data acquired from aircraft and spacecraft were described and illustrated. The potential usefulness and limitations of such procedures in various developing countries were considered.

7. Fish, wildlife and recreation resources

38. On a global basis the increased importance in wildland areas, of the fish, wildlife and recreation resources must be considered so that the management of such lands will no longer be directed merely toward the maximizing of timber, forage and livestock.

39. Several specific instances were considered in which remote sensing from aircraft and spacecraft has been used effectively as an aid to inventory, develop, monitor and manage the fish, wildlife and recreation resources of wildland areas. Special

consideration was given to the problems associated with the making of "cost/benefit" analyses when the above-mentioned resources are being regarded as a part of the total "resource complex" of an area.

D. Remote sensing activities in various countries and institutions

1. Bangladesh

40. Two representative remote sensing projects being conducted in Bangladesh were described by a participant from that country in the workshop: (a) the monitoring of land use patterns in the northern part of the country using sequential Landsat imagery in both black-and-white and colour composite form; and (b) the analysis of offshore sediment problems in the coastal areas of southern Bangladesh where sequential space photos clearly reveal that new islands are forming, growing, and eventually becoming part of the mainland.

2. Bolivia

41. Mr. Carlos Brockman, in his capacity as Chief of the Programme on satellite technology and natural resources in Bolivia, described the various remote-sensing related activities in the country. He pointed out the advantages resulting from the fact that the nadir points for each Landsat-2 pass are almost identical with the nadir points for the corresponding Landsat-1 pass, and placed nine days out of phase with respect to the latter. He stated that more than 99 per cent of Bolivia has now been covered by cloud-free Landsat imagery. The relative advantages and limitations associated with the acquiring of Landsat data from the EROS Data Center and acquiring them from the Brazilian Space Center were discussed. A copy of the Landsat imagery mosaic at a scale of 1:9,000,000 for all of Bolivia was given to each attendee and selected portions of it were interpreted in detail. Similar treatment was given to a single frame of Landsat imagery of a representative portion of Bolivia on which both planimetric and topographic information derived by other means had been overprinted. Mr. Brockman stated that a project designed to accomplish land use mapping of all of Bolivia from Landsat data is now 60 per cent complete. He showed several examples of this work and of specific instances in which Landsat imagery, when suitably enhanced by either optical or electronic means, had greatly facilitated the making of resource inventories in Bolivia.

3. Canada

42. Mr. Lawrence Morley, Director of the Canada Center for Remote Sensing described various activities of that Center with emphasis on systems design. He discussed the problems that were encountered as Canada sought to establish a national remote sensing center, and he engendered much discussion as to the likelihood that similar problems will be encountered within the various developing nations represented at the workshop. He noted the tendency for a country's governmental agencies to become involved in remote sensing programmes at an earlier date and on a larger scale than its universities and private industrial components. Reasons for this tendency in various countries were considered in detail.

43. The organization and activities of the Canada Center for Remote Sensing were then described after which numerous slide examples of Landsat imagery of Canada were interpreted in terms of their natural resources.

4. India

44. The two major agencies of India that are involved with remote sensing are (a) the national remote sensing agency, and (b) the Department of Space.

45. A participant from the national remote sensing agency (Mr. Rao) described the two phases of a remote sensing project that is being conducted in the Nabha area of India. Phase 1 pertains to a portion of the area that is essentially non-forested. Within it both Landsat data and aerial photographs are being used to map land use, soil types, and water resources (including drainage). In phase II a second area is being studied from a multidisciplinary standpoint and remote sensing is being used for purposes of cartography, geology, forestry and the making of coastal studies. Both manual and computer assisted methods of data analysis are being employed. As a by-product of these studies, good collaboration with the Geography Department of the University of Hyderabahd has been established and that department will play an important future role, especially in the analysis of remote sensing data by human means.

46. The Department of Space in India, as described by two delegates from it to this workshop, contains four remote sensing-related groups concerned, respectively, with (a) satellite and launch vehicle technology, (b) launch pad and mission control facilities, (c) satellite fabrication and the integration of satellite payloads, and (d) a space applications centre that is concerned with remote sensing data analysis, communication satellites, and payload fabrication. The two-fold remote sensing objective of India's Department of Space is (a) to develop equipment and techniques for the acquisition, processing, analysis, utilization and management of remotely sensed data; and (b) to achieve a satisfactory status of training and development with respect to (1) sensors, (2) imagery processing, and (3) image analysis.

47. A stimulating classroom discussion followed these presentations.

5. Indonesia

48. The Director of the Remote Sensing Institute of Jakarta, in his capacity as a participant in the workshop, described the various activities of his Institute, which is mainly geared to the use of Landsat as well as aircraft data. The three-fold objective of that Institute is (a) to help Indonesia by exploiting international space relations, (b) to co-operate in remote sensing activities with various Indonesian universities, and (c) to provide remote sensing-related resources to Indonesia's potential user agencies. In addition he described the four types of processing and analysis equipment that are being used by remote sensing scientists in Indonesia and presented the rationale that prompts the desire of the Indonesian Government to establish a receiving station for Landsat data in or near Jakarta.

6. Iran

49. As described by one of the workshop delegates from Iran, there are five national objectives in Iran related to remote sensing: (a) to install a receiving station for Landsat data; (b) to develop associated data processing facilities; (c) to procure and properly use digital analysis equipment; (d) to develop suitable remote sensing-related data management systems; and (e) to integrate the above four activities into an intelligent long-term master plan. It is anticipated that, within five years, there will be a complete Remote Sensing Centre in Iran with approximately 600 employees. A training institute also is to be established in conjunction with various universities with a view to offering both master's and doctoral degrees in remote sensing.

7. Israel

50. The two participants from Israel described a representative project dealing with the preparation of a geologic map of Israel from a study of aerial and space photos. Several new and significant lineaments were discovered even though the entire area had previously been closely studied on the ground for many years by highly competent geologists.

8. United States

(a) ERIM (Environmental Research Institute of Michigan)

51. ERIM's over-all activities and objectives that are related to remote sensing were described by its principal official in this field, Mr. Marvin Holter. These include: (1) determining, through a combination of basic research and production-oriented activities the usefulness of remote sensing observations based, respectively, on the spectral, spatial and temporal properties of various earth resource features; (2) analysing the various factors that influence the amount and nature of the radiation that can be remotely sensed (e.g., the intensity and spectral characteristics of the illuminant; the absorption, scattering and emission characteristics of the atmosphere; the spectral absorption scattering, reflectance and emission of both the atmosphere and the various earth resource features; and the effects of different illumination and observation angles); (3) exploring the relative advantages of colour photography versus multiple-frame black-and-white photography acquired in essentially the same wavelength bands; and (4) investigating the uses and limitations of visible light photography, thermal infrared imagery and imagery acquired in the microwave region either actively (by means of side-looking airborne radar equipment) or with the use of a passive microwave radiometer.

52. Three additional presentations by ERIM participants dealt, respectively, with (1) the use of remote sensing in studying regional water pollution problems that are attributable to non-point sources; (2) bathymetry studies conducted by ERIM personnel in conjunction with Jacques Cousteau and his associates; and (3) determining the usefulness, for purposes of earth resource inventory, of various combinations of multiband and multipolarization imagery.

(b) EROS Data Center

53. The two participants from the EROS Data Center first described the capabilities of that Center for providing remote sensing data to personnel from developing countries. Types of products, prices and ordering procedures were thoroughly discussed, as well as the time delay likely to be involved in the receipt of the various products. Also stressed was the fact that, for many areas, not only space-acquired data but also that acquired from aircraft can be ordered from the EROS Data Center.

54. Next an indication was given of the training activities that are engaged in by personnel of the EROS Data Center and mention was made of the opportunities for remote sensing-oriented personnel from the developing countries to receive on-the-job training at the Center.

55. Thereafter the two participants from ERIM provided two days of highly informative workshop-type exercises in the derivation of geologic and hydrologic information from Landsat data, aerial photography and associated ground truth. These exercises are alluded to in the sections of this report dealing, respectively, with geology and hydrology.

(c) Purdue University

56. Most of the remote sensing-related activities at Purdue University, in West Lafayette, Indiana are co-ordinated through its Laboratory for the Applications of Remote Sensing (LARS). The Director of that laboratory, Mr. David Landgrebe, described some of those activities. Special emphasis was placed on describing the various programmes that have been developed at LARS to permit computer-assisted analyses to be made of remotely sensed data. The decision criteria applied to these programmes, all of which are based on digitized values of scene brightness, were fully explained.

57. Work being done by LARS in various developing countries, including Bolivia, were discussed by Mr. Roger Hoffer. Thereafter two workshop-type exercises were presented by LARS personnel. Both exercises dealt with the development of decision criteria for use in the classification of earth resources by means of computer assisted analysis.

(d) University of California

58. During the past several years six campuses of the University of California have been actively involved in a NASA-funded project entitled "An integrated study of earth resources in the State of California using remote sensing techniques". All of these activities were reported upon at this workshop and workshop exercises based upon a portion of this work were incorporated into the instructional programme.

59. In addition, personnel of the remote sensing groups of the University of California have engaged, either individually or collectively, in a number of remote sensing projects designed to inventory the natural resources of developing countries. These have ranged from short-term one-time efforts in Colombia, Australia, Argentina and New Guinea to long-term and continuing efforts such as those associated with project RADAM, so called because it seeks to use radar imagery to inventory the entire earth resources complex of the Amazon Basin.

60. In addition to these developing-country assignments, the remote sensing capabilities of the University of California continue to be used domestically in a variety of activities including the inventory of (1) the total area of land under irrigation in the Sacramento Valley; (2) the resource complex on more than 2 million acres of range land owned and managed by the US Bureau of Land Management; (3) the distribution of woody fuels in the brushlands of southern California; and (4) the volume of timber, by species, size and condition class in both the Plumas National Forest of California and the Sam Houston National Forest of Texas.

61. Each participant in the workshop who cared to have it was issued a copy of each of the reports dealing with the above topics; in addition workshop-type exercises were administered dealing with certain of these topics as listed elsewhere in this report. A day-long field trip to one of the University's campuses, viz. the one at Riverside, was made by the delegates to this workshop for the purpose of observing remote sensing equipment and operations.

(e) Others

62. While many other groups in the United States are very active in remote-sensing projects, the ones listed above are considered representative. In addition several private industrial groups also earn their livelihood, to one degree or another, through the performance of remote sensing-related activities. Among those which provided representatives for a portion of the meeting were the following: Eastman Kodak Company; International Business Machines, Inc; General Electric Corporation; Earth Satellite Corporation; and Information Systems Incorporated.

III. OBSERVATIONS AND RECOMMENDATIONS

63. At the final discussion, participants expressed their gratitude to the United Nations and International Astronautical Federation for the organization of the workshop and all those whose efforts made the seminar a success, especially to Mr. R. N. Colwell, who was a co-ordinator of this workshop.

64. Concerning future seminars and workshops under the space applications programme, the participants requested that attention be given to more practice and training in using equipment. Participants taking part in such exercises should be divided into small groups according to their fields of interest.

65. The participants felt that preference should be given to more problem solving or discipline-oriented seminars on a regional basis and the establishment of permanent training facilities attached to regional centres for remote sensing could best satisfy the training requirements of developing countries.

ANNEX

LIST OF TECHNICAL PAPERS SUBMITTED

1. Bartov, Y.; Y. Mimran; and I. Karcz; "Lineaments in the Coastal Plain of Israel". Ministry of Commerce and Industry Report MM/4/76, 13 pages; 15 plates. 1976.

2. Canada Center for Remote Sensing, "An Economical Approach to ERTS Data Reception and Dissemination", by E. Shaw. Technical Note 74-2, 10 pages. 1974.

3. Canada Center for Remote Sensing, "A Remote Sensing Compatible Land Use Activity Classification", by Robert A. Ryerson and David M. Gierman. Technical Note 73-1, 18 pages. 1975.

4. Canada Center for Remote Sensing, "Image Analysis Equipment in Use at the Canada Center for Remote Sensing", by J. Cihler and R. P. B. Thompson, 16 pages. 1975.

5. Canada Center for Remote Sensing, "Information Bulletin on Airborne Operation", 89 pages plus Appendices. 1975.

6. Canada Center for Remote Sensing, "Satellite Imagery Interpretation: Suggestions for Laboratory Design", by T. T. Alfoldi and R. A. Ryerson, Cospar Technical Manual No. 5, 19 pages. 1975.

7. Choudhury, A. M.; A. Azim; S. Ahmed; and S. Rahman, "A Study of the Haor Areas of Sylhet-Mymensing Districts with ERTS Imageries (Winter Crop Estimation)", In Proceedings of First Annual Bangladesh Science Conference, 5 pages. 1976.

8. Choudhury, A. M., "How Much Land Can We Get From The Sea?" Bangladesh Space and Atmospheric Research Center, Special Publication, 5 pages. 1976.

9. Colwell, Robert N., et al., "Monitoring Earth Resources from Aircraft and Spacecraft", NASA Special Publication No. 254, 190 pages. 1969.

10. Colwell, Robert N., "An Integrated Study of Earth Resources in the State of California Using Remote Sensing Techniques", Semi-Annual Progress Report, Space Sciences Laboratory, University of California, 210 pages. 1975.

11. Colwell, Robert N., "Introduction to Remote Sensing", Reprint of Chapter I of the Manual of Remote Sensing of the American Society of Photogrammetry, 26 pages. 1975.

12. Colwell, Robert N., "Classification of Forest Lands on Aerial Photographs", University of California, School of Forestry and Conservation", 3 pages. 1976.

13. Colwell, Robert N., "Some Basic Considerations in the Remote Sensing of Natural Resources", A syllabus of reference material compiled for use in the UN/IAF Workshop at Anaheim, California, 182 pages. 1976.

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SPFCIAL STUDY NO. 2

by

Robert N. Colwell

Contributors: Sharon Wall
David Huston
Dennis Noren
James Sharp
Stephen Titus
Vincent Vesterby

Introduction

Since this special study deals with an important part of California's water inventory and water management problem, it is closely related to work which our group has been doing under the multi-campus NASA grant study that is dealt with in the main body of this report. Nevertheless, it is designated here as a special study, because it was not funded under our grant but under NASA Contract No. NAS 5-20969 bearing the title "An Inventory of Irrigated Lands for Selected Counties within the State of California Based on Landsat and Supporting Aircraft Data".

By way of placing this special study in proper perspective the following points are considered essential:

1) California receives an annual average of 200 million acre-feet of precipitation.

2) Because most of this precipitation occurs in the winter months and most runoff occurs in areas with low demand for water, the state of California has built large scale systems, as under the California Water Plan, for the purpose of storing water and eventually of transporting it from areas of surplus to areas of scarcity.

3) The California Department of Water Resources (DWR) is charged with the "control, protection, conservation and distribution of California's water in order to meet present and future needs for all beneficial purposes in all areas of the state".

4) The DWR carries out this responsibility through a statewide planning program which, in part, includes periodic reassessment of existing and future demands for water and period reassessment also of local water resources, water uses and the magnitude and timing of the need for additional water supplies that cannot be supplied locally.

5) To meet these needs the DWR has been performing a continuing survey on a 5 to 10 year cycle to monitor land use changes over the state that will be indicative of changes in water demand.

6) Because of the costs (an estimated 150,000 per year) and manpower efforts involved, only a portion of the state is surveyed during a given year. Hence, at any given time water resource data applicable to the various portions of the area of concern have differing degrees of currency, the information having been collected in some areas only recently and in others as much as 5 to 10 years previously. The shifting time base applicable to information from the various components makes it very difficult to compile figures that will reflect water demand throughout the entire state for any given point in time.

7) Even before the advent of the present study, some remote sensing was used in the DWR data collection effort. Specifically, conventional aerial photography was acquired, in any given year and only on a one-date basis, for each of the counties that were scheduled for an updating of information relative to water demand. From interpretation of the aerial photography and the use of supplemental field inspection, the DWR is able to estimate the acreage of irrigated land in that county as of the date of photography. However, for want of multi-date photography during the growing season DWR is not able to determine either (a) individual types of crops (or crop groupings) that are of significance because of differing demands for irrigation water, or (b) areas in which, through a practice known as "multi-cropping", a given area is made to produce two or more crops in succession in the same growing season, thereby imposing in most instances increased water demands per acre per season.

In view of the foregoing it was considered probable that the repetitive monitoring capabilities offered by the Landsat I and Landsat II vehicles would provide a practical source of information that could become a valuable supplement to the DWR surveys that have just been described. More specifically, the primary objective of the Irrigated Lands Project (ILP) was to develop an operationally feasible process by which the California Department of Water Resources (DWR) could use information derived from the analysis of Landsat imagery, together with supporting large scale aerial photography and ground data to obtain irrigated acreage statistics on a regional basis (i.e., statewide). The methods which personnel of our Remote Sensing Research Program were able to develop preliminarily under this project are now in the process of being demonstrated/tested in a survey of ten California counties (13,745,000 acres). In the 10-county test, three dates of Landsat imagery have been chosen for the estimation: June (when the best insight on small grain acreage is obtained) August (when the maximum canopy coverage for many crops is exhibited) and September (when evidence is best obtained of a multiple cropping sequence). Landsat I color composites, printed at a scale of approximately 1:154,000, were produced for each of the ten counties on each of the selected dates. County boundaries and areas excluded by DWR from the

study (e.g. orchards which, because of their greater degree of permanence are already well mapped) were then annotated on the imagery.

A three phase sample design with cluster units was chosen for the ILP study, and involved Landsat interpretation, large scale aerial photo interpretation, and ground measurement. The sample units at each phase were a subsample of the sample units at the previous phase. Since estimates are required on a county basis, a stratification by county was also used. A single FORTRAN program was written to compute the three-phase estimates and the associated variance estimateds.

Manual interpretation techniques for the Landsat imagery and large scale aerial photography were developed by the RSRP and demonstrated to DWR personnel at several training sessions. With the training provided, DWR became actively involved in interpreting both the Landsat imagery and the large scale aerial photography. A preliminary test based on one of the counties, indicates that there is a correlation of 0.951 between the aerial photo interpretation and ground truth data, and of 0.950 between the Landsat imagery interpretation and the aerial photo interpretation.

SPECIAL STUDY NO. 3

THE INTERPRETABILITY OF VEGETATION RESOURCES ON VARIOUS IMAGE TYPES ACQUIRED FROM EARTH ORBITING SPACECRAFT

by

Robert N. Colwell

Summary of NASA-funded work performed by participants in the present Grant and reported upon at the SPSE Symposium on Image Analysis and Evaluation which was held in Toronto, Canada, during the period of July 19-23, 1976.

SUMMARY

An investigation was conducted to determine the usefulness of imagery acquired by each of several remote sensing systems for identifying and delineating natural vegetation types both in the Colorado Plateau of northwestern Colorado and in the Alice Springs area of central Australia. In addition, similar tests were made with respect to cultivated vegetation types growing on agricultural croplands in the Great Valley of northern California. Imagery used in each of the three test areas included (1) that acquired by the Skylab Earth Resources Experimental Package--EREP (using the S190A and S190B sensor systems) and (2) that acquired by the Earth Resources Technology Satellite--LANDSAT (using the multispectral scanner-MSS). For one of these areas, viz. the Alice Springs area, additional imagery was available including SKYLAB's color-enhanced imagery produced from S192 scanner data and also ektachrome space photography of excellent quality that had been acquired by the Gemini V astronauts. Hence both of these additional types of imagery were incorporated in the comparative analysis that was made of the Alice Springs area.

Depending upon which aspect of the test was being performed, a total of from 10 to 40 moderately experienced image analysts were used all of whom were completing, or had recently completed, a basic course in photo interpretation as taught by the present writer at the University of California. Each image analyst was first permitted to practice with various representative image examples on each of which vegetational features of known identity had been labelled. Thereafter the image analyst attempted to establish the identity of similar selected features (each marked with a dot and number on an acetate overlay) on each type of imagery, according to a prescribed set of instructions. The sequence in which the image analysts were allowed to study the various image types covering the same area was randomized. This was done in order to eliminate bias from an analyst's having seen the "best" image type first, -- a practice which would have facilitated his identifying

the same features on subsequent image types that were basically less interpretable.

In addition, more experienced image analysts made more detailed analyses of these image types and thus arrived at subjective evaluations with respect to specific questions not addressed by the formal testing.

More than 50,000 individual test responses were generated from these tests, thus providing a solid statistical base for assessing the relative interpretability of each image type. The test responses were scored using ground data obtained from on-site visits and from the interpretation of large scale aerial photographs on which most of the selected features were easily identifiable. Statistical analyses were performed using the test results, and conclusions were reached regarding the relative utility of each system and image type.

For all three geographic areas the following eight image types were used: SKYLAB S190A color and color infrared imagery; SKYLAB S190A black-and-white imagery in the red and near-infrared spectral regions, respectively; SKYLAB S190B high resolution color imagery; LANDSAT color composite imagery (specifically, the color infrared simulation made by using bands 4, 5 and 7 of the multispectral scanner) and LANDSAT black-and-white imagery from bands 5 and 7, respectively, of the multispectral scanner. For the three test sites LANDSAT and SKYLAB imagery was acquired on the following dates:

Test Area	System	Date (1973)
Great Valley Area of Northern California	LANDSAT MSS SKYLAB EREP	May 28, September 13 June 3, September 12
Alice Springs Area of Central Australia	LANDSAT MSS SKYLAB EREP	July 31, November 2 August 12, December 14
Colorado Plateau Area of Northwestern Colorado	LANDSAT MSS SKYLAB EREP	August 16 August 3 and 8

In addition, (for the Alice Springs Area only), SKYLAB EREP S192 multispectral scanner data which had been acquired on August 12 and December 14, 1973 and which had then been color enhanced by combining representative green, red and near-infrared bands, was included in the tests as was GEMINI V ektachrome photography that had been taken on 27 August, 1965.

The following statements summarize the main results of this study that were obtained from tests conducted with the moderately experienced group of image analysts.

1. For the identification and delineation of natural vegetation types:

(a) The SKYLAB S190A color infrared imagery was better than all other image types tested.

(b) Even though the spatial resolution of the SKYLAB S190B imagery was more than two-fold better than that of the S190A system, this potential advantage was more than offset by the fact that the S190B system provided only conventional color film, while the S190A system provided color infrared ("infrared ektachrome") film on which there were decidedly superior color contrasts among vegetation types.

2. For the identification of agricultural crop types:

(a) When crops were in the late-spring seasonal state (May and June) the SKYLAB S190 color and color infrared image types were the best of the eight image types tested, and were about equally interpretable.

(b) When crops were in the late summer seasonal state (September) the SKYLAB S190A color infrared imagery and the LANDSAT color infrared simulation (made by the optical combining and color coding of bands 4, 5 and 7) were the best, and were about equally interpretable.

(c) In this instance, as in 1 above, superior color rendition (as provided by these two image types) proved to be more important than superior spatial resolution (as provided by the S190B system).

(d) Beyond this, a particular film type would be specified only if high identification accuracy were required for a particular crop type.

3. For the overall identification of both natural and agricultural vegetation complexes, the eight image types were rated as follows (from best to worst):

   SKYLAB S190A Color IR
   LANDSAT (simulated Color IR) composite
   SKYLAB S190B Color
   SKYLAB S190A Color
   SKYLAB S190A black-and-white (near-infrared)
   LANDSAT black-and-white band 7 (near-infrared)
   SKYLAB S190A black-and-white (red)
   LANDSAT black-and-white band 5 (red)

4. The following statements apply to results obtained from detailed analyses that were made by more experienced image analysts:

(a) Stereoscopic interpretation of SKYLAB imagery was significantly better than monoscopic interpretation of it, especially when the interpretation was done by those who understood the relationship between vegetation types and topography.

(b) SKYLAB S190A color IR and S190B color, in that order, were judged to

be best for the <u>mapping</u> of natural vegetation types. (This task entails not only the making of spot identifications but also the delineation of boundaries between types.)

(c) Both the LANDSAT and the SKYLAB S190A systems were considered adequate for regional crop survey studies (such as regional drought assessment from season to season), but imagery of higher resolution, such as that provided by the SKYLAB S190B system, was found to be necessary for making most crop management decisions.

(d) Delineation of rice-growing areas was accomplished with 90.7% accuracy using a late spring LANDSAT color composite and 82.1% accuracy using summer SKYLAB S190A color IR imagery.

(e) Color infrared was the most useful for evaluating crop vigor and plant stress.

(f) For both natural and agricultural vegetation complexes, the fineness with which the classification could be performed (in terms of the smallness of the area than can be recognized and delineated as to type) was found to improve significantly with the spatial resolution of the remote sensing system. In this respect SKYLAB S190B imagery was found to be superior to SKYLAB S190A imagery, which in turn was superior to LANDSAT imagery.

(g) In virtually all respects the interpretability of both the GEMINI V color photography and the SKYLAB S192 color composite imagery ranked with, but slightly after, the SKYLAB S190A color photography.

(h) Multidate color enhancement was found to be valuable for assessing year-to-year changes in the locations and areal extent of rice fields.

(i) Requirements with respect to the frequency of opportunities for coverage that should be potentially available with any satellite-based remote sensing system are difficult to specify in any given agricultural area without a thorough study of prevailing weather conditions and also of the times when critical events occur in the development of crops in that area. Nevertheless it can be generalized that in most agricultural areas the potential for a 9-day coverage cycle, through the tandem use of LANDSAT 1 and LANDSAT 2, is vastly superior to the potential for only an 18-day coverage cycle, as when only one of these vehicles is available.

(j) Also with respect to timeliness, delays of more than a few days in receipt of data from satellite systems can cause severe problems in their use for crop management and marketing decisions. For regional surveys, on the other hand, delays of up to several weeks can be tolerated.

SPECIAL STUDY NO. 4

USEFULNESS OF OUR NASA-FUNDED REMOTE SENSING RESEARCH PROGRAM TO THE KERN COUNTY WATER AGENCY

by

Stuart T. Pyle, Engineer-Manager, KCWA

Explanatory note by the Principal Investigator: The following material is included because (1) it provides an indication of the great interest, on the part of a representative group of water resource managers, in work done to date under this NASA-funded grant by our remote sensing scientists, (in this specific instance by scientists of the Geography Remote Sensing Unit on the Santa Barbara campus), and (2) it reflects a willingness that is expressed by many such resource managers to continue providing contributory support to our studies. The purpose of such support (as illustrated here), is to maximize the prospect that the remote-sensing based procedures which we are developing can be used to an ever-increasing extent in the future in solving practical problems related to the inventory and management of California's water resources.

KERN COUNTY WATER AGENCY
4114 Arrow Street, P.O. Box 58
Bakersfield, California 93302

November 9, 1976

File Nos. 9.3.51
400-25

Mr. Robert Colwell
Center for Remote Sensing Research
University of California, Berkeley
School of Forestry and Conservation
145 Mulford Hall
Berkeley, California 94720

Re: NASA Remote Sensing Research Program, Kern County, California

Dear Mr. Colwell:

This Agency has been cooperating with the University of California, Santa Barbara, in the Remote Sensing Program under a grant from NASA. The program will determine the feasibility of using the remote sensing techniques for classifying vegetative cover, which is used as a factor in our floodflow hydrology. The current feasibility study is of the Lake Isabella area and will be expanded to an area of about 4,000 square miles if the method is shown to be feasible.

The peak floodflows are used in the Agency's floodplain management program, which includes review of subdivisions, parcel maps, building permits, and design of flood control facilities. We also plan to use this data for the Flood Insurance Program.

We feel this technique would be beneficial to other agencies such as the Soil Conservation Service, Bureau of Land Management, Forest Service, Corps of Engineers and Bureau of Reclamation to fulfill a broad spectrum of inventory requirements for watershed management.

This Agency has expended approximately $3,000 on the ground truth surveys and $1,000 was paid to Robert Sasso of UCSB for the purchase of LANDSAT images, computer compatible tapes, and data analysis computer time. This is in addition to the $5,000 NASA grant to the University.

Mr. Robert Colwell
Page Two
November 9, 1976

If the remote sensing technique proves to be feasible, this Agency would be in a position to provide additional funding as the method will result in a substantial decrease in the need for field investigations. The actual amount of Agency funds that would be available is not known at this time since our budget is not prepared until February. This will give you and NASA the opportunity to submit cost estimates and local funding requirements prior to our budget preparation. The funds for such a project is subject to approval by our Board of Directors.

If more information is needed, please contact George Ribble, Paul Fuller or Darrell Sorenson of this Agency.

Yours very truly,

Stuart T. Pyle

Stuart T. Pyle
Engineer-Manager

DKS:PDF:ep
xc: Mr. Jack Estes, UCSB w/Attachs.
Mr. Robert Sasso, UCSB w/Attachs.
University of California
Geography Department
Remote Sensing Unit
Santa Barbara, CA 93106

SPECIAL STUDY NO. 5

CRITIQUE BY A NASA CONSULTANT OF WORK DONE TO DATE UNDER OUR NASA GRANT

by

Peter A. Castruccio
Consultant to NASA and President, Ecosystems International Inc.

Explanatory note by the Principal Investigator: The following material is included as an example of the objective evaluation and constructive criticism from which the participants in our NASA Grant are able to benefit by virtue of NASA's willingness to arrange for reviews of our work by qualified consultants.

ECOsystems
International Inc.
Box 225 Gambrills, Md. 21054
(301) 987-4974/6
Cable: Ecointl Baltimore

May 19, 1976

Professor R. N. Colwell
Center for Remote Sensing Research
School of Forestry and Conservation
145 Walter Mulford Hall
University of California
Berkeley, CA 94720

Dear Professor:

Following our discussion in Baltimore of May 8, let me first apologize for being so late in sending you this critique of Berkeley's report, "An Integrated Study of Earth Resources in the State of California Using Remote Sensing Techniques." The truth is that I found the report so interesting that I simply had to read it all in spite of its bulk of probably close to 1,000 pages.

The report is truly outstanding. It goes a long way towards meeting what I believe was the original intent of NASA, namely the demonstration of the practical application of remote sensing, and the assessment of its practical "worth" (which the report expresses well in terms of cost effectiveness, i.e. reduce costs to accomplish important tasks from LANDSAT vis-a-vis those of more conventional methods).

I found the following items worthy of note:

1. The idea of testing the sensitivity of hydrologic water supply models to changes in principal parameters is very good. I think its particular merit lies in the fact that the major role of LANDSAT in water resources is the detection and measurement of dynamic changes. Professor Algazi clearly sets forth the fact that the hydrologic response of watersheds varies significantly with season. The obvious consequence is that a good model can not be fixed, but change its parameters as a function of time. Before the advent of LANDSAT such changes were either not incorporated, or were simply estimated. Aerial photography is clearly too expensive to allow its recurrent use several times a year: while it serves as a good base upon which to superimpose LANDSAT information, it is only the latter which allows precise, frequent and economic updating of the watershed's characteristics and thus the accurate prediction of water supply.

2. The work on runoff from snow, particularly the two aspects of: a) the stage method of improving estimate of area, and b) the attempt to correlate reflectance with water content, may eventually prove of significant benefit to the ongoing snow ASVT.

3. The section on evapotranspiration is particularly informative by virtue of the fact that it sets forth in one place and concisely most of the important evapotranspiration models. I may suggest adding perhaps a comparison of the accuracies achieved between models, and hopefully some ground rules for the optimal selection of a model for specified conditions and times of the year.

4. The work on image interpretation, which appears in various sections, is particularly valuable in that it supplies a good overview of the state of the art and practical instructions of how to perform this function. If your resources permit, it may be worthwhile to attempt a comparison between results and costs achievable with machine interpretation, purely visual interpretation, and mixes of the two.

5. The presentation of the costs (or rather the man-power application) involved in interpretation appears thorough and well documented. The importance of this subject suggests that perhaps a future report contain a section devoted entirely to summarizing these costs and comparing them with costs incurred by employing aerial photography and conventional methods.

6. The chapter on water demand is particularly interesting because the method employed appears very economical. I may suggest in this connection a comparison between water demand estimation from remote sensing and available records of consumption. If one could demonstrate that the method set forth is not only economical but also of adequate accuracy (as perceived by the water resources planners) this could become a truly outstanding achievement for LANDSAT.

7. The discussion by the social sciences group of the roles of "land users" and "non-land users," as well as their conclusions as to the recent developments in water resources mangement in California, is illuminating. One could perhaps extrapolate the trends that they set forth into some prediction for the role of satellite remote sensing in more and more integrated and interrelated resource management activities in the 1980's. A substantiated and cogent

effort in this direction would, I believe assist in the planning of the role of future LANDSAT systems: not only, but also in the planning of integrated and mutually supportive observations from various satellite systems.

In summary, let me repeat that the report appears to be a truly outstanding piece of work: I wish to thank you for sending me a copy.

Sincerely yours,

ECOSYSTEMS INTERNATIONAL, INC.

Peter Castruccio

Peter A. Castruccio, President

rp

cc: Mr. Leonard Jaffe
Mr. Joseph Vitale

CHAPTER 8

SUMMARY

Robert N. Colwell

CHAPTER 8

SUMMARY*

Robert N. Colwell

8.0 In this integrated, multi-campus study, California's water resources continue to be the primary resources investigated. We have concentrated our efforts on determining the usefulness of remote sensing in relation to two aspects of California's water related problems: (1) those pertaining to water supply in northern California, (dealt with primarily by personnel of the Davis and and Berkeley campuses, as reported upon in Chapters 2 and 3, respectively); and (2) those pertaining to water demand in central and southern California, (dealt with primarily by personnel of the Santa Barbara and Riverside campuses, as reported upon in Chapters 4 and 5, respectively). In addition, the socio-economic, cultural and political considerations that relate to the management of California's water resources continue to be investigated by the Social Sciences Group on the Berkeley campus, as reported in Chapter 6. Finally, in Chapter 7, an account is given of various special studies which, while being highly relevant to certain of the objectives being sought in our grant-funded studies, were not themselves funded through the grant, itself.

8.1.0 The following facts are described in Chapter 1 of this progress report:

8.1.1 At NASA's request, the primary focus of our research recently has been changed from one of conducting remote sensing-related research to one of preparing "procedural manuals". The primary objective in preparing such manuals is to achieve technology acceptance. More specifically, the objective is to maximize the prospect that potential user agencies will adopt modern remote sensing techniques as an aid to the inventory and management of water resources, not only in California, but elsewhere as well.

8.1.2 Despite this change of focus, we have been able to progress toward the completion of those research aspects which will serve to establish the validity of the various step-by-step procedures which we are in the process of developing for inclusion in the manuals.

*This summary of our 4-campus activities, like that appearing in each of our previous grant reports, is of necessity quite lengthy. The interested reader is nevertheless encouraged to read it in its entirety, the better to appreciate the integrated nature of this multicampus study and to select portions meriting more detailed reading, depending upon his own specific interests.

8.1.3 The reader will find in this progress report the first iteration of several Procedural Manuals, each describing the specific way in which remote sensing can be used advantageously to inventory some water-related attribute, such as areal extent of snow, water content of snow, water demand in agricultural areas, etc. Thus, the rather sizable overall document will be for use of those concerned with all aspects of water resource management (both the supply and the demand aspects) while each of its various subdivisions, when made to stand alone, will better serve the needs of those concerned with only one limited aspect or another of this management problem.

As an additional aspect of our NASA-approved plan, (1) by 1 May 1977 we intend to bring to completion, or very nearly so, all of our remote sensing studies that pertain specifically to water resources, and (2) during the one-year period immediately thereafter as we near the time of termination of the grant, we intend to concentrate on the preparation of Procedural Manuals that deal with remote sensing as an aid to the inventory and management of the entire "resource complex" of an area -- i.e. not just its water resources, but also its timber, forage, agricultural crops, soils, minerals, fish, wildlife, livestock, and recreational resources.

With respect to the preparation of these more comprehensive Procedural Manuals we recently have had discussions with various resource managers including (1) California's Regional Forester of the U.S. Forest Service; (2) the Supervisors of various U.S. National Forests in California; (3) their counterparts in California's State government; and (4) those concerned with resource management.

8.1.4 Although in some instances it is preferable from the intended user's standpoint for the Procedural Manual to deal with remote sensing as applied to only a single resource, such as water, in other instances it should deal with remote sensing as applied to the inventory and management of multiple resources or, indeed, to the entire "resource complex".

8.1.5 Procedural Manuals of the latter type will be made (during the one-year period beginning on 1 May, 1977) primarily by three components of our multicampus integrated team: (1) the Geography Remote Sensing Unit on the Santa Barbara campus; (2) the Geosciences Remote Sensing Group on the Riverside campus, and (3) the Remote Sensing Research Program on the Berkeley campus. During that same period our Social Sciences Group also will be assisting in the preparation of the relevant manuals.

8.1.6 By mutual agreement, the remote sensing team at Davis, under the leadership of Dr. Ralph Algazi, will not contribute to the preparation of Procedural Manuals during the one-year period that begins on 1 May, 1977. Instead his grant-funded efforts will be entirely in support of the ASVT that is jointly administered by NASA Goddard and the U.S. Army Corps of Engineers dealing with remote sensing as an aid to the estimation of water supply.

8.2 The following facts are summarized in Chapter 2 of this report:

8.2.1 The work of the Algazi group on the Davis campus of the University of California continues to deal primarily with uses of remote sensing in relation to the inventory of water supply. Specific aspects of the work performed by that group during the present reporting period are as follows:

8.2.1.1 Implementation and sensitivity analysis of a watershed model. The effect on estimates of monthly volume runoff was determined separately for each of the following parameters: precipitation (i.e., rainfall and snowmelt); evapotranspiration; lower zone and upper zone tension water capacity; imperviousness of the watershed; and percent of the watershed occupied by riparian vegetation, streams, and lakes. The most sensitive and critical parameters were found to be precipitation during the entire year and springtime evapotranspiration.

8.2.1.2 Determination as to which of the hydrologic parameters used in the model are amenable to remote sensing inputs. As evidenced by the above findings the two most important parameters to acquire by remote sensing are precipitation and evapotranspiration. Hence efforts are continuing to maximize the usefulness of remote sensing in measuring these parameters, area-by-area.

8.2.1.3 Development of techniques for predicting snowmelt runoff based on digital processing of satellite images. The physical quantities that are of greatest significance in the modeling of basin snowmelt are temperature, albedo, water content, and the areal extent of snow, the latter being further stratified in terms of the elevation, slope, and aspect of the area wherein the snow is present. NOAA satellite returns have been used by Algazi, et al, as the primary source of input data with respect to snow.

8.2.1.4 Basic studies of image processing techniques pertinent to remote sensing applications. Emphasis has been given in these studies to the making of geometric corrections of satellite images as necessitated by such factors as panoramic distortion, earth rotation, skan skew, satellite velocity, satellite altitude and attitude changes, and changes in the velocity of rotation of the scanning mirror. Details relative to the making of certain of these corrections appear in Appendices A and B of Algazi's Chapter (Chapter 2) of the present progress report.

8.3 The following facts are reported in Chapter 3 of this report:

8.3.1 Work performed by personnel of the Remote Sensing Research Program on the Berkeley Campus of the University of California, like that of the Algazi group at Davis, continues to deal primarily with uses of remote sensing in relation to the inventory of water supply. Specific aspects of the work performed by that group during the present reporting period are as follows:*

8.3.1.1 The summarizing of findings to date with respect to the uses that can be made of remote sensing in making estimates of water supply, whether in a local drainage basin or throughout an entire watershed.

8.3.1.2 The development of remote sensing-aided procedures, based on that summary, for estimating various important components that are used as input to hydrologic models dealing with water supply. For areas such as our test sites in the Sierra, these components include the areal extent of snow, the water content of snow, the amount of solar radiation, and the loss of water to the atmosphere by evapotranspiration.

8.3.1.3 The preparation of procedural manuals, each of which will describe, for one or more of the above components, the stepwise process which might best be followed by managers of water resources in using remote sensing as an aid to acquiring information with respect to that component.

8.3.2 The RSRP group concludes that, with only a little more refinement the methodology which that group has developed for a remote sensing-aided system to estimate the various components of a water yield model will give timely, relatively accurate, and cost-effective estimates over snow-covered areas, on a watershed-by-watershed basis.

8.4 In Chapter 4 of this progress report the following facts are emphasized:

8.4.1 During the current reporting period, personnel of the Geography Remote Sensing Unit (GRSU) on the Santa Barbara Campus (authors of Chapter 4) have been concentrating their research efforts on the following water demand related topics:

8.4.1.1 The development of manual and digital remote sensing techniques capable of producing cost-effectively most of the information that is needed in making water demand prediction for agricultural areas, whether in California or elsewhere.

8.4.1.2 More specifically, the development of remote sensing techniques for the generation of agricultural water demand information that will facilitate resource management by the Kern County Water Agency (KCWA) in the southern portion of California's San Joaquin Valley.

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*Close cooperation with Algazi's group continues on all of these aspects.

8.4.2 In the attempts that have been made to generate this agricultural water demand information, definitive experiments have been performed on the usefulness of remote sensing in quantifying each of the prediction variables, including estimates of acreage by crop type, physiographic variables, and meteorological variables.

8.4.3 In the above studies care has been exercised to ensure that efforts by the Santa Barbara group were complementary to, and not duplicative of, those engaged in by the Algazi group at Davis, personnel of the RSRP at Berkeley, or our remote sensing team at Riverside.

8.4.4 Sufficient success has been achieved in the above activities to permit the Santa Barbara group to prepare a preliminary version of its "Procedural Manual for the Use of Remote Sensing Techniques in Deriving Cropland Information for Water Demand Predictions". That procedure is given in Section 4.3 of the present progress report.

8.5 As described in Chapter 5 of this progress report, during the present reporting period remote sensing scientists on the Riverside campus of the University of California have been concentrating their efforts on the following water demand related topics, and with a view to producing appropriate procedural manuals: Chapter 5 of this Progress Report deals with studies conducted by remote sensing scientists on the Riverside campus, relative to water and other resource allocations in southern California.

8.5.1 These studies have led to the following accomplishments during the present reporting period:

8.5.1.1 Production of a Procedural Manual for the use of remote sensing in Land Use Mapping. In its present form that manual will be evaluated by potential users after which a final, and well illustrated, version. will be prepared.

8.5.1.2 An analysis of the potential use of Landsat temporal data to monitor changes in irrigated land. The test area for this study is the Perris Valley region of the Upper Santa Ana River Drainage Basin.

8.5.1.3 A study on the uses of remote sensing to provide inter-census estimates of the human population of specified areas in southern California.

8.5.2 In addition to the above, the Riverside group is in the process of documenting the kinds of software needed to maximize the usefulness of remote sensing for land use mapping by automated means.

8.6.0 In Chapter 6 of this progress report personnel of our Social Sciences Group on the Berkeley campus have presented some very cogent observations on socio-economic factors that can govern the acceptance of modern remote sensing technology.

8.6.1 In seeking to serve as the interface between remote sensing technology and the society that it has been designed to serve, (i.e. between the technical and the user communities) the Social Sciences Group has pursued the following specific objectives:

8.6.1.1 To achieve a better understanding of the institutional dynamics and mechanisms through which water policy decisions are made and implemented;

8.6.1.2 To seek out and investigate potential users and uses of remote sensing;

8.6.1.3 To establish and maintain rapport with persons responsible for the management of California's water resources;

8.6.1.4 To delineate, observe and assess the social forces bearing on decisions about water resource management; and

8.6.1.5 To identify and study the factors, institutional, bureaucratic, historical, legal, and psychological, which influence receptivity among members of the water management community to new information sources.

8.6.2 In making such investigations the Social Sciences Group has continued to work closely with personnel of other groups that are participating in our integrated study, particularly those working under the Remote Sensing Research Program on the Berkeley campus and those comprising the Geography Remote Sensing Unit on the Santa Barbara campus.

8.6.3 One concept developed for the first time in the present report of the Social Sciences Group relates to the "canopy of social resources" (viz. institutions, capital, skills, and information) required to make natural resources useful. In this context, the group concerns itself especially with the changes required (in institutions, capital, skills, and information) to ensure the adoption and wise use of modern remote sensing technology by those who manage water resources.

8.6.4 The Social Sciences Group has identified, and studied in some detail, six features that can significantly influence a user's receptivity to applications involving remote sensing:

8.6.4.1 Complexity of the technology.

8.6.4.2 Specificity, i.e. the degree to which the technology addresses the user's particular problems.

8.6.4.3 Availability, in terms of both the ease and speed with which the user can obtain outputs from the new technology.

8.6.4.4 Reliability with respect to both (a) the quality and consistency of the data and (b) the continued availability of the data source.

8.6.4.5 Accessibility, a factor which is closely related to availability, but which relates more specifically to constraints imposed on access to the data because of military security, political sensitivity, institutional confidentiality, or guarantees against the invasion of privacy; and

8.6.4.6 Compatibility of the new data source with existing information and decision "models" in which the data would need to be incorporated.

8.6.5 Borrowing from NASA's terminology, a new concept of the "multispectral view" is developed by the Social Sciences Group in its present progress report. In this view resource issues appear as signatures on four perceptual "bands" that break incoming information into physical-environmental, economic, social, or political categories.

8.6.6 The present report of the Social Sciences Group continues with the identifying and analyzing of three emerging trends on the social landscape that are likely to affect our understanding of resource issues and thereby our acceptance of resource-related remote sensing technology.

8.6.6.1 An increased awareness of new publics spawned by a mountain of federal and state legislation concerned with "social justice";

8.6.6.2 An increased awareness of the need for preserving and, if possible, enhancing man's environment; and

8.6.6.3 An increased awareness that the earth's natural resources are in limited supply .

8.6.7 Chapter 6 of the present progress report concludes with a discourse on the evaluation methodology that should be used in assessing a new technology such as remote sensing.

8.7.0 In Chapter 7 of the present progress report, as in our previous reports, several special studies are included. Such studies are so designated because, although highly relevant to certain of our NASA grant objectives, they have been conducted with other than grant funds.

Five such studies appear in the present report.

a. A report on the United Nations/IAF sponsored Workshop on Remote Sensing that was held in Anaheim California during the period 27 September - 8 October, 1976 with those who are participants in the present grant serving both as Workshop Coordinators and principal instructors.

b. A study involving the remote sensing of irrigated lands in California, as requested by the California Department of Water Resources.

c. A very extensive and intensive test to determine the interpretability of vegetation resources on various image types acquired from earth-orbiting spacecraft.

d. An unusually thoughtful commentary relative to the usefulness of our NASA-funded Remote Sensing Research Program to the Kern County Water Agency, as prepared by the Engineer-Manager of that very large and progressive agency, and

e. A critique by one of NASA's consultants relative to work which we have done to date under the grant.

8.7.1 A reading of the above special studies, as contained in Chapter 7 of the present progress report, will provide the interested reader with a much more comprehensive view of the potential usefulness, both in California and elsewhere, of various aspects of the work which we have been doing for the past several years under this NASA-funded grant.